PHYSICS

PART II

SCIENCE FOR MIDDLE SCHOOLS

NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING

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PHYSICS

PART II

Board of Writers

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Foreword

There is today a ferment in science education. The rapid developments in science and technology in recent years have made it necessary to think of changes in curriculum, textbooks and methods of teaching science in our schools. While this is generally true of all countries in the world, it is more so for India, if we wish to bridge the distance which separates us from the advanced countries. Unless our pupils in the schools learn more science and better science, it will not be possible for them to help the country in developing at a faster rate. But to do this in the same time span of ten or eleven years in the school, it is necessary to think of new ways of teaching science. If a scientific attitude has to develop, its base must be built on conceptual understanding and reasoning rather than on retention and reproduction of bits of information.

Science in some form or the other, either as General Science or as Every Day Science, is being taught in all our schools at the middle stage. It has, however, been felt by all concerned that this is far from adequate, as it does not provide a firm foundation for the understanding of basic concepts of Physics, Chemistry and Biology. The Education Commission (1964-66) has observed that "the general science approach to the teaching of science which has been very widely adopted at the elementary stage during the last 10 years has not proved successful as it tends to make science appear somewhat formless and without structure and runs counter to its methodology. A disciplined approach to science learning would, it is felt, be more effective in providing the necessary scientific base to the young pupils."

The Unesco Planning Mission which visited this country in 1964 also made similar recommendations for effecting improvements in the teaching of Science and Mathematics in Indian schools. Following these recommendations, the Department of Science Education in the National Council of Educational Research and Training has undertaken a major project to upgrade Science and Mathematics teaching starting from the middle school stage. A new curriculum in Science and Mathematics for the middle stage as separate disciplines of Physics, Chemistry, Biology and Mathematics has been prepared and textbooks, teachers' guides and curriculum guides are being developed. It is expected that this curriculum would equip those who leave school at the close of the middle stage with enough basic knowledge of the sciences and their applications. The middle stage covers three years of school education. All the materials developed under this project are being tried out in selected schools and on the basis of the experience gained, the instructional materials are being refined and further developed for application throughout the country. The first part of

series of text materials, teachers' guides and curriculum guides has already been published and is being used in some selected schools of Delhi and in the Central Schools all over the country. The present series of text materials is for the second year course of the middle stage. The curriculum has a practical bias and the knowledge of science is given through experimental activities to be performed by teachers and pupils. Every care has been taken to present a correct and up-to-date view of science and to see that the examples used are drawn from Indian situation. A variety of indigenous equipment and apparatus have been designed and produced by the Central Science Workshop of the National Council to make better instructional materials available to teachers.

The National Council is grateful to Unesco Experts who assisted the Department of Science Education on this project. It is also thankful to the Director of Education, Delhi Administration, who very kindly provided facilities to try out the curricular materials in selected schools in Delhi. The National Council will welcome comments and suggestions from teachers and others interested in science education for the improvement of these materials.

New Delhi
20 January, 1968

SHIB K. MITRA
Joint Director,
National Council of Educational Research and Training

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	Page	For	Read
1.	35, Article 15, Column 2, Line 2	forces will be parallel	forces may be regarded as parallel
2.	52, Column 2, Line 10	The distance between	The shortest distance between
3.	65, Line 4 from bottom	type of pulley	type of lever
4.	69, Column 2, Line 6 from bottom	to move the body	to move the body uniformly
5.	81, Item 4	Vav is the speed of	Vav is the average speed of
6.	98, Item 6	even whem it is made of thick glass	when it is thin glass
7.	120, Column 2, Line 8 from bottom	1 Kcl	1 Kcal
8.	123, Item 10	$E=\frac{q_u}{q}\times 100\%$	$E=\frac{q_u}{q_t}\times 100\%$
	Item 11	427 kgwtm—1 Kcal 4.18 J—1 Cal	427 kgwtm=1 Kcal 4.18 J=1 Cal
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10.	131, Column 1, Line 3	latent heat of fusion	heat of fusion
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11.	142, Table	269	—269
		253	—253
		196	—196
		183	—183
		33	—33
	Column 2, Line 4 from bottom	latent heat of	heat of
12.	143, Column 1, Line 2	the latent heat of	the heat of
	Column 2, Lines 6-8	—540 cal/g —204 cal/g —84 cal/g	540 cal/g 204 cal/g 84 cal/g
	Column 1, Line 12	Kcal/g	Kcal/kg
	Column 2, Line 15	is divided by	is denoted by
13.	145, 1st line	the latent heat	the heat
14.	146, Article number	§ 73	§ 74
15.	149, Item 11	fusion of the body	fusion of the substance
	Item 14	crystallization of the body	crystallization of the substa
16.	150, Item 17	form	from
	Item 18	The speed of	The process of
	Item 24	same	some

Contents

CHAPTER VI. TRANSITION OF SUBSTANCES FROM ONE AGGREGATE STATE INTO ANOTHER

CHAPTER I

Mechanical Motion

§ 1. Motion

You have seen different types of transport system such as the bullock-cart, cycle, bus, motor car, etc. You have seen trains, ships, and aeroplanes. Some of them move slowly, others fast. A man on a cycle can easily overtake a bullock-cart. Motor cars move faster than either of them. Observing these moving objects, you get an idea of motion (Fig. 1.1).

Motion means the change of position of a moving body in relation to some fixed objects. When we consider the motion of terrestrial bodies, we usually take the stationary objects such as trees, houses, etc. on the surface of the earth as reference points. You may have noticed how the water in a river moves compared to its banks. Similarly, for a moving train we take the telegraph poles fixed on the ground as reference points. Aeroplanes and rockets give you an idea of how fast they can move. **This continuous change of position of a body with respect to another is called mechanical motion.** The distance through which a body moves in a particular time is called its displacement.

Draw a line on a blackboard. The line thus traced out will be either straight or curved, depending upon the way the chalk is moved on the blackboard (Fig. 1.2). If the path followed by a moving body is straight the motion is said to be rectilinear and if it is curved the motion is curvilinear.

While bursting crackers and other fireworks like improvised rockets etc. during Diwali, you must have noticed sparks flying off from them in different directions. Some fly directly in straight lines towards you while others follow curved paths. Have you ever gazed at the sky on a starry night? If so, you must have often seen a bright line moving across the sky.

This is the trail blazed by a shooting star as it falls towards the earth (Fig. 1.3).

Fig. 1.1. A man, a bullock-cart, a cycle, a motor car and an aeroplane move with different speeds

Fig. 1.2. The path traced out by a chalk on the blackboard

Fig. 1.3. Trail of a shooting star as it moves across the sky

§ 2. Translatory and Rotatory Motion

The motion that we have been talking about can be either translatory or rotatory. From your everyday experience, you know that the wheels of a cycle rotate round the axle but the cycle moves forward.

Thus the cycle has both rotatory and linear motion. When water is drawn from a well, the bucket is tied to a rope that passes over the pulley. The motion of the bucket as it moves up is different from the motion of the pulley. The bucket moves in a straight line but the wheel rotates round the axle. The carpenter's drill and the motion of a cork-screw are examples where we find two types of motion. These clearly indicate that motion can be either translatory or rotatory.

When loads are either lifted or lowered by a crane (Fig. 1.4*b*), the motion of the load is translatory because each part of the body follows the same path. The drawer of a table, as it is opened, is another example of translatory motion.

In Fig. 1.4*a*, the motion of the bucket as it moves up is shown; here each part of the bucket follows a similar path. If the path described by each part of the moving body is similar and remains equal for any interval of time, the motion of the body is said to be translatory. In translatory motion it is not necessary that the path should always be straight.

Fig. 1.4 (a). The motion of a bucket, when it is being drawn from the well

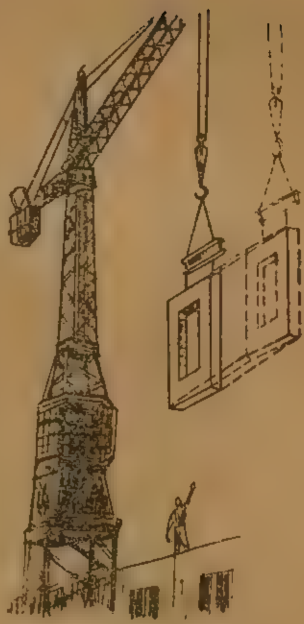
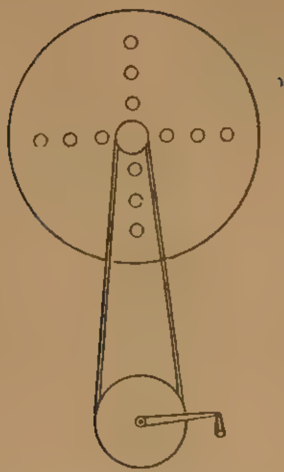


Fig. 1.4 (b). A crane lifting a load

Rotatory Motion

Rotatory motion can be clearly understood from the following. Take a circular piece of a white cardboard and make some black dots on the diameters at different distances from the centre. Rotate the cardboard at a high speed. You cannot now distinguish between the



(a)

(b)

Fig. 1.5. (a) A cardboard disc with dots drawn on its diameter
(b) When the disc is rotated you see a number of circles having different radii

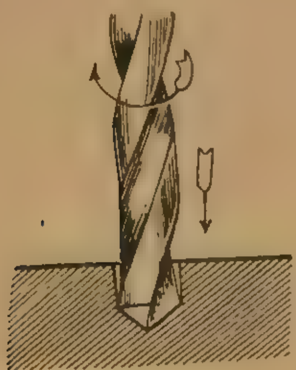


Fig. 1.6. The rotatory and translatory motion of a drill

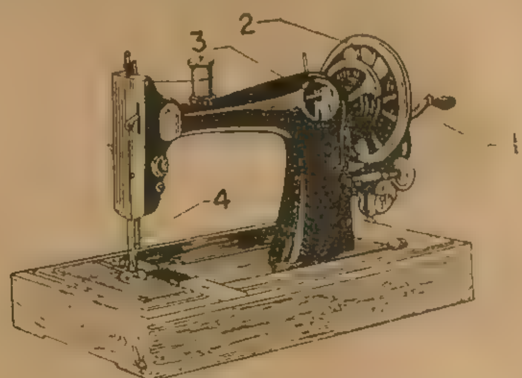


Fig. 1.7. A sewing machine showing different parts possessing different types of motion

different dots. It will appear to you that a number of circles having different radii are moving as shown in Fig. 1.5. This shows that **different points of a body in rotatory motion move along different circumferences. The centres of these circumferences lie in a stationary straight line which is called the axis of rotation.**

In some cases we find that the motion of a body is either only translatory or only rotatory. But there are examples where both translatory and rotatory motions occur simultaneously. For example, when a screw is either fixed to a body or taken out by a screw driver,

it has both translatory as well as rotatory motion. Fig. 1.6 shows rotatory and translatory motions of a drill. Have you ever observed the working of a sewing machine when something is being stitched? The handle-1, the wheel-2, and the shaft-3 rotate but the needle-4 and the needle holder move up and down in a straight line (Fig. 1.7).

Exercise

1. Two motor cars are moving on the road with the same speed and maintaining the same distance between them. Name objects compared to which each one of them is at rest or in motion.
2. What type of path is described by the tips of hour and minute hands in a wrist watch ?
3. What is the type of motion of a body falling freely under the action of gravity? Is it the same as, or different from, the motion of a window pane of a ventilator when opened or closed ?
4. Give two examples each of translatory and rotatory motion.
5. Explain the difference between the types of motion in a fodder cutting machine and the fodder that is being cut.
6. Explain the motion of the file when used as a planer for making the surface plane (Fig. 1.8).

Fig. 1.8. The movement of a planer

7. Describe the working of a lathe in a workshop and illustrate the different types of motion of its different parts.
8. What is the type of motion of a spinning top? Is it translatory or rotatory?

§ 3. Time

A man, who wants to travel from one place to another by train but does not reach the station at the correct time, will miss the train. The work in the office will not be carried out properly if we ignore time completely. If mills and factories are not run on time, the production will be much less. You have perhaps heard frequent announcements of time over the radio giving commencement of any programme.

Time is measured in terms of the intervals at which a particular phenomenon repeats itself. For example, you all know that the earth is rotating around its own axis when it revolves round the sun. It always takes the same interval of time to complete one rotation.

The position of the sun seems to change if we keep it under observation from morning till evening. Early in the morning it is near the horizon and when it reaches the highest point, we have mid-day or noon. In the evening as the sun sets in the west, it is again near the horizon.

The time interval between two consecutive noons is called one solar day. However, solar day is not constant. It varies from day to day. In order to find out the time for one solar day, its average (mean) value is calculated from the total time for one year and then dividing it by the number of days in a year. The mean solar day is then divided into 86400 equal parts. One such small part is taken as the unit of time. This unit is called a second.

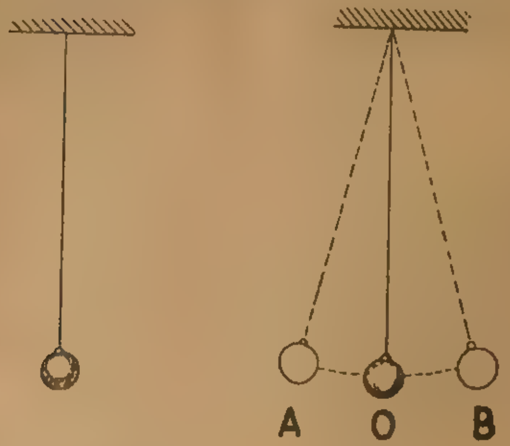
When the mean solar day is divided into twenty-four equal parts, each part is called one hour. An hour is further divided into sixty parts to obtain one minute. One sixtieth part of one minute is one second. The instrument that measures time is called a clock.

Let us try to do the following experiment in the laboratory.

Experiment

Take a heavy metallic bob and suspend it from a fixed support by means of a thread as shown in Fig. 1.9*a*. When it is freely suspended and is in equilibrium, it is vertical. Mark the rest position of the bob. This arrangement is known as a simple pendulum. If the bob is displaced slightly by just pulling it and then allowing it to move freely, it makes a to and fro motion. It starts from the position of rest O, goes to one extreme end A,

and then goes past O to B, and comes back to the position O again (Fig. 1.9*b*). This complete to and fro motion is known as one oscillation.



(*a*) (*b*)

Fig. 1.9. A pendulum: (a) pendulum is at rest (b) oscillating pendulum

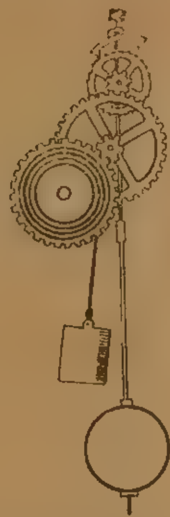


Fig. 1.10. Wall clock showing the working of the control wheel

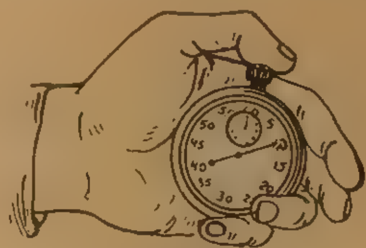


Fig. 1.11. Stop-watch

The time taken by the pendulum for one complete oscillation is called the time-period. The time-period of a simple pendulum remains constant so long as its length is not altered. If the length of the pendulum is increased the time-period also increases. It is less when the length of the pendulum is decreased.

A wall clock is shown in Fig. 1.10 where the working of the control wheel with the pendulum is shown.

There is no pendulum in small watches. Do you know how it shows time ? There is a small spring which is wound first. The spring, while unwinding, makes the wheel move in a to and fro motion. It

goes from left to right and then from right to left. Time can be measured accurately up to one second with this type of watch. For measuring time to less than one second, a special type of watch called stop-watch is used. The stop-watch is shown in Fig. 1.11.

There is a small knob at the top which is used for winding the watch. If this knob is pressed, the second hand starts moving on the dial where the timings are given. By pressing the knob the watch can be stopped whenever desired and the second hand comes back to its original position when pressed a third time. Time can be measured accurately up to one-tenth of a second by using this stop-watch.

§ 4. Uniform and Non-uniform Motion

When a train starts from a station, it moves very slowly and gains speed only after sometime. As it approaches another station it first slows down before stopping.

When an aeroplane takes off from an airport it moves over a long distance on the runway in order to gain speed. Once it is airborne, it moves faster and faster.

From the examples given above, it is quite clear that, whether it is a train or an aeroplane, the distance travelled in a particular time in the beginning is different from that after it has been in motion for sometime.

Any object that moves through equal distances in any equal intervals of time, however small the interval may be, is said to be in uniform motion.

When a body moves over unequal distances in equal intervals of time, it possesses non-uniform motion.

Let us do an experiment to understand the difference between uniform and non-uniform motions.

Experiment

Take a small trolley which can move freely on a smooth table. A pulley is fixed at one end of the table. A string fixed to the trolley passes over the pulley and carries a weight at the other end. A sheet of white paper is spread on the table. A small bottle fitted with a stopcock is filled up with ink and is kept on the table as shown in Fig. 1.12*a*.

Open the stopcock slightly. When the trolley starts moving after it is pushed with a small force, drops of ink will leave marks on the white paper. The distance between these successive drops of ink will remain the same and the motion of

the trolley is said to be uniform. It shows that a body possesses uniform motion when it moves through equal distances in equal intervals of time.

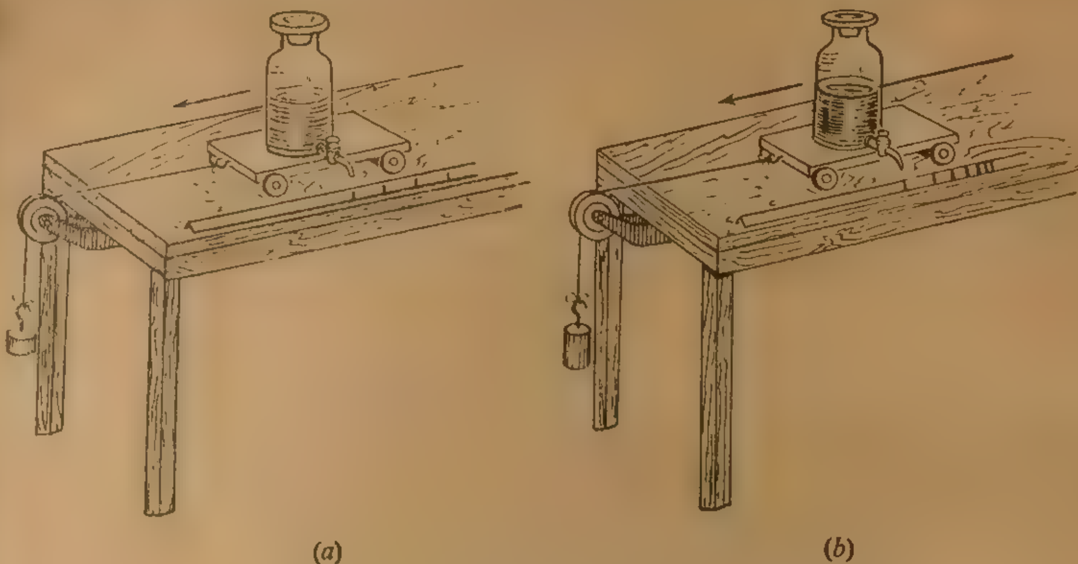


Fig. 1.12. Showing (a) uniform motion of a trolley (b) non-uniform motion of a trolley

The motion of a body, whether uniform or not, can be found out by measuring the distance travelled by the body. If a body moves through a distance of 100 metres in one minute, another 100 metres in the next minute and then 50 metres more in the next 30 seconds, it possesses uniform motion.

In the same experiment, as shown in Fig. 1.12*b*, the trolley can be moved faster by increasing the weight and it will no longer be necessary to push it for starting the motion. If the stopcock is now opened slightly and the distances between the successive inkdrops are measured again, they will not remain the same. It is quite evident from this experiment that the trolley does not move through equal distances in equal intervals of time and its motion is said to be non-uniform. Another familiar example of non-uniform motion is a motor car when it starts or stops. In everyday life non-uniform motion occurs more frequently.

Exercise

1. Explain the type of motion in each case : a carpenter's file and the planer. Is it uniform or non-uniform ?

2. Give a simple method of measuring time.
3. Take a string one metre long and suspend a stone or some other heavy bob and measure the time period by a watch.
4. Calculate the number of oscillations your pendulum will make during a period of 5 minutes.
5. Give three examples each for uniform and non-uniform motions.

§ 5. Speed

Now you have some idea of motion and time. We have already discussed about the cycle, bullock-cart and motor car in §1. We have said that the man on a cycle moves faster than the bullock-cart. The motor car moves faster than either of them. What we have meant by 'moving faster' is that the distance covered by the bullock-cart in a particular interval of time is much less than the distance the cyclist will be able to cover at the same time. Motor cars will cover a much greater distance; aeroplanes will take very little time in going from one place to another.

The distance travelled in unit time is called speed.

Suppose a car moves through a particular distance of 1 km in one minute; then its speed is 1 km per minute.

In case of uniform motion the speed of a body can be determined by measuring the distance through which a body moves in a fixed interval of time.

$$\textbf{Speed} = \frac{\textbf{distance}}{\textbf{time}}$$

if we denote the distance by s and time by t, and speed by V, we have,

$$V = \frac{s}{t}$$

Example:

(*i*) A motor car travels through 400 kilometres in 10 hours. Find out the speed of the car.

$s = 400$ km
$t = 10$ hr
V—?

$$V = \frac{s}{t} = \frac{400\text{ km}}{10\text{ hr}} = 40\frac{\text{km}}{\text{hr}}$$

(*ii*) A body moves through a distance of 95 cm in 5 seconds. Find the speed of the body.

$s = 95$ cm
$t = 5$ sec
V—?

$$V = \frac{s}{t} = \frac{95\text{ cm}}{5\text{ sec}} = 19\text{ cm/sec}$$

The speed can be expressed in different units. Such as cm/sec, km/hr, metre/minute, etc. But generally in physics, the unit of speed is taken as cm/sec.

Example:

A motor car travels 72 km/hr. Express the speed of the car in metre/minute and cm/sec.

$V = 72 \frac{km}{hr}$ $\qquad V\left(\frac{m}{mt}\right) = 72 \frac{1000\ m}{60\ mt}$

$V\left(\frac{m}{mt}\right) - ? \qquad = 1200 \frac{m}{mt}$

$V\left(\frac{cm}{sec}\right) - ? \qquad V\left(\frac{cm}{sec}\right) = 72 \frac{100000\ cm}{3600\ sec}$

$= 2000 \frac{cm}{sec}$

Thus the speed of the car is 1200 m/mt or 2000 cm/sec

There is an indicator in a motor car and other transports which gives the speed of the car. It is generally connected to the wheels. The pointer indicates the speed in a meter called speedometer (Fig. 1.13).

From the above solved examples, it is seen that to campare the speeds of two different transports, both the speeds must be expressed in the same unit.

The following table gives the speeds of some living and non-living objects.

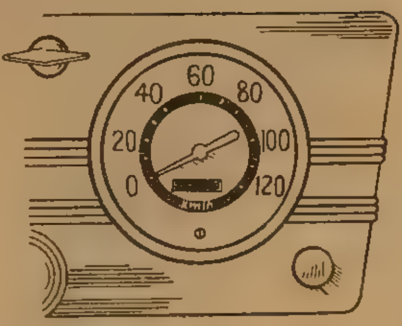


Fig. 1.13. Speedometer in a motor car

Snail	0.15 cm/sec.
Man walking on foot	1.2-1.8 m/sec.
Bullock-cart	1.7 m/sec.
Cheetah (fastest animal)	29 m/sec. approximately.
Mail train (maximum)	56 m/sec.
Duck Hawk (fastest bird)	78 m/sec.
Aeroplane	210 m/sec.
Sound (in air)	332 m/sec.
Jet plane	663 m/sec.
Bullet of a rifle	860 m/sec.
Sound (in water)	1450 m/sec.
Moon (Round the earth)	1 km/sec.
Satellite	8 km/sec.
Earth round the sun	29.9 km/sec.
Light and radio waves	300,000 km/sec.

A train moves uniformly with a speed of 15 m/sec. It means that the train moves through a distance of 15 metres in one second. The distance covered by the train at the end

of the next second will be 30 metres.

This can be expressed in the following way:

In 1 second the distance travelled $= 15$ metres

In 2 seconds ,, $= 15 \frac{m}{sec.} \times 2$ sec. $= 30$ metres

In 3 seconds ,, $= 15 \frac{m}{sec.} \times 3$ sec. $= 45$ metres

In 4 seconds ,, $= 15 \frac{m}{sec.} \times 4$ sec. $= 60$ metres

Thus, the distance travelled by the train in 10 seconds will be

$15 \frac{m}{sec.} \times 10$ sec. $= 150$ metres.

In order to find out the distance travelled by the body in a definite time, one has to multiply the speed by time.

$$\boxed{\text{distance} = \text{speed} \times \text{time}}$$

If we denote distance by s, the speed by V and time by t we have,

$$\boxed{S = V \times t}$$

Example:

A pedestrian has a speed of 2 km/hr. He reaches home after 5 hours. Find out how much distance he has travelled.

$V = 2 \frac{km}{hr}$

$t = 5$ hr

S — ?

$S = V \times t$

$= 2 \frac{km}{hr} \times 5$ hr

$= 10$ km

Exercise

1. A train has a speed of 60 km/hr. Express it in m/sec.
2. The sound of a thunder was heard 6 seconds after the flash of lightning. How far was the lightning?
3. How much distance will you cover in $1\frac{1}{2}$ hours if you go with a speed of 3 m/sec on a cycle ?
4. Your house is at a distance of 8 km from your school. If you want to reach home in 4 hours, what should be your speed ?

§ 6. Average Speed

When the motion of the body is non-uniform, we consider its average speed for finding out the distance travelled by the body in a particular time.

For example, the distance between Delhi and Bombay is 1380 km. A train takes 23 hours to travel from Delhi to Bombay. In these 23 hours the speed of the train goes

on changing. Sometimes it moves slowly, sometimes faster. If the motion of the train were uniform the speed would have been 60 km/hr.

This speed is known as average speed. **The average speed can be found out by dividing the distance travelled by the time taken.**

$$\boxed{\textbf{Average speed} = \frac{\textbf{total distance}}{\textbf{total time}}}$$

If we denote time by t, the total distance covered by s, and the average speed by V_{av}, we have,

$$\boxed{V_{av} = \frac{s}{t}}$$

Example:

The distance between Delhi and Calcutta is 1450 km. A train moves with a speed of 58 km/hr. How many hours will it take to reach Calcutta ?

$$S = 1450 \text{ km}$$
$$V_{av} = 58\frac{\text{km}}{\text{hr}}$$
$$t - ?$$

$$\because \quad V_{av} = \frac{s}{t}$$
$$\therefore \quad t = \frac{s}{V_{av}} = \frac{1450 \text{ km}}{58\frac{\text{km}}{\text{hr}}} = 25 \text{ hr}$$

If the average speed is given and the total distance covered by the body is also known, then the time taken can be easily found out.

Exercise

1. An aeroplane moves through a distance of 1400 km with a speed of 860 km/hr. Calculate the time taken by the aeroplane in covering the given distance.
2. A man walks through a distance of 50 metres in 6 seconds and in another 15 seconds he moves only a distance of 30 metres. What is his average speed in covering the total distance?
3. A train moves with an average speed of 19 m/sec in the first 200 metres, and the next 360 metres with an average speed of 12 m/sec. What is the average speed of the train?
4. In the playground a boy runs 1500 metres in 2 minutes and 12 seconds. Calculate the average speed of the boy.

§ 7. Inertia

If a book is kept on a table, and if it is not displaced from its position by any person, it will always remain there. In order to lift it or displace it slightly from its position of rest, one has to apply some force on it.

A sheet of ordinary paper is spread on a table and a tumbler filled with water is kept on it as shown in the Fg. 1.14. If the paper

Fig. 1.14. The paper is pulled suddenly so that it can be taken out without disturbing the tumbler

is taken out by pulling it suddenly with a hand, the tumbler will not be disturbed at all and will remain in its position.

From the examples given above, it is quite clear that bodies at rest will have a tendency to remain so, if they are not displaced from their position of rest by applying some external force.

When a cycle is moving and the road is very smooth, the cycle moves some distance without moving the pedals before it stops. If the floor of a room is very smooth, a ball moves to a longer distance before it comes to rest. Such moving bodies remain in motion for some time before they come to rest.

Newton's First Law

This phenomenon was first discovered by the Italian scientist Galileo who observed the motion of various bodies.

The great English scientist Isaac Newton (1642—1727) introduced Galileo's observation as one of the fundamental laws of mechanics.

If no force is acting upon a body, the latter may either be at rest or in uniform motion in a straight line.

The same law enables us to assert that if a body is at rest or in uniform translatory motion, no force is acting upon it.

It is possible to formulate the law in a different way.

Any body remains at rest or in uniform rectilinear motion unless the body is acted upon by a force.

This law was called the law of inertia. The tendency of a body to

remain at rest or in uniform rectilinear motion is called inertia. It is a property common to all bodies in nature. We come across inertia whenever a body is in motion and suddenly it is stopped or it changes the direction of its motion, or changes its speed. When we start running we have to make a certain effort to gain speed, and once we are running, it is impossible to stop instantaneously. Everyone knows how difficult it is for a running person to abruptly change direction. Because all bodies possess inertia it is equally impossible to set in motion the different parts of a lathe machine or to stop them instantaneously. Inertia is very important in the transport system. A moving motor car, tram or train cannot be stopped instantaneously. Even if the brakes are applied to the wheels and their rotation stops, the vehicle continues to move on for some time and its wheels slide along the road. Everyone knows that passengers bend in the forward direction of the vehicle's motion and even may fall sometimes when the vehicle is suddenly brought to a stop. Similarly, they fall backwards when the vehicle starts moving abruptly or increases its speed suddenly.

It was mentioned above that every body in nature possesses inertia; it is, however, the mass of a body that determines the amount of inertia. The bigger the mass of a body the greater is its inertia and *vice-versa.* Everyday observation shows that actually it is the mass of the body in a state of rest which determines the amount of effort needed to move that body. The larger the mass the greater is the effort. Similarly, it is more difficult to stop a loaded wagon than an empty one though they move at the same speed.

Exercise

1. A person in getting down carelessly from a moving bus tends to fall forward. Why?
2. Dust from a piece of cloth comes off, if it is beaten by a stick or is shaken. Why?
3. There are two brakes in a cycle, one in the front wheel and the other in the back one. Which brake should be applied first for stopping the cycle?
4. A cardboard is kept on a glass and a coin is placed on it. The cardboard is then moved suddenly by a sharp movement of your finger as shown in Fig. 1.15. Explain what happens.

Fig. 1.15. The cardboard is moved studdenly by a sharp movement of the finger

5. Which hammer head is fixed more easily, if you knock one end of the handle at the same speed—a heavy hammer or a light one?
6. Why is the collision of loaded motor cars more dangerous than that of unloaded ones? (The speed is equal).
7. Why are the bases for machines and machine tools made massive and heavy?

§ 8. How Uniform Translatory Motion is Achieved

We know that if a force does not act on a body, it is either at rest or moves uniformly in a rectilinear motion. But in practice some kind of force always acts upon a body (gravity, friction and so on). It is impossible to remove these forces. Then how can we make a body move uniformly in a straight line? Let us conduct an experiment.

Two dynamometers attached to a block experience equal forces acting on it along the same straight line but in opposite directions. The block will remain at rest. Consequently, a body will remain at rest not only when no force is acting upon it but also when it is acted upon in a straight line by two equal and opposite forces.

Let us now see the effect of two equal and opposite forces acting on a moving body, for example, on a motor car. A motor car starts off and gathers speed owing to a pulling force which is developed by the engine. But with the increasing speed, the resistance to the car's motion increases, which is in a direction opposite to the motion of the car. At a certain speed the total resistance created by the contrary

air current and the friction of the wheels along the road will be equal to the pulling force. As soon as the pulling force and the force of resistance become equal they will balance each other, as they are always in opposite directions and act in one and the same straight line. The combined action of these forces will be equal to zero. From that moment the motor car will be moving uniformly and in rectilinear motion. Uniform rectilinear motion will also be characteristic of the steamship if the pulling force of the engine is equal to the resistance of air and water.

Hence, when a body is moving uniformly and in rectilinear motion, the resistance force will be equal to the pulling force.

Two equal and opposite forces acting in a straight line upon a body are called balancing forces. Thus a state of rest and state of uniform rectilinear motion can be observed in two cases: either no force acts upon a body or a body is acted upon by balancing forces.

Hence, summarizing, Newton's first law may be formulated as follows:

Any body remains at rest or in uniform rectilinear motion, if it is either not acted upon by any force or is acted upon by balancing forces.

§ 9. Friction

Let us make an arrangement as shown in Fig. 1.16. Let a cylinder start moving from a given height of

Fig. 1.16. Movement of the cylinder on the inclined plane

the inclined plane and cover a distance along the horizontal surface made of glass. Here it is seen that the speed of the cylinder along the horizontal surface gradually decreases and ultimately the cylinder stops after covering a certain distance. If the same experiment is repeated with the wooden and sandy horizontal surface, separately, it is found that in each case the same cylinder starting its motion from the same height of the inclined plane does not cover the same distance on the horizontal surface as in the previous case. The distance covered is greatest in the case of glass surface, less in the case of wooden surface and least in the case of sandy surface.

We have discussed motion earlier. But whenever a body is

made to move over the surface of another body, it does not have a free motion. According to Newton's first law, if the speed of a moving body changes gradually, there must be a force acting upon the body.

This force which resists the motion of a body moving over another body and acts in a direction opposite to the direction of motion of the body is known as the frictional force. In practice no surface is perfectly smooth and there is always some unevenness, i.e., elevations and depressions. A typical rough surface where the unevenness is photographed on a magnified scale is shown in Fig. 1.17(*a*). The friction is

Fig. 1.17 (a). Unevenness of a rough surface shown on a magnified scale

always due to the roughness of the material surfaces in contact. When such a rough surface is dragged over another similar one, the elevations of one surface get entangled into the depressions of the other, thus opposing the motion. If the surfaces are perfectly smooth and polished, then there is very little force of friction to oppose the motion. But even then the molecular attraction between the two surfaces will always give rise to some amount of friction though it is negligibly small.

You must have noticed that it is difficult to drag a heavy trunk along the surface of the ground. Do you think this difficulty is mainly due to the weight of the trunk? Besides the weight of the trunk there is another force acting between the ground and the surface at the bottom of the trunk.

The force acts in a direction opposite to that in which the trunk is pulled. This force of friction between two surfaces when the bodies are at rest, is known as static friction. When an external force is applied to a body so that it slides over another surface, the frictional force developed is called sliding friction. On the other hand, if a body rolls over another surface, it is known as rolling friction. For example, the wheels of a bullock-cart, motor car or a train roll over another surface but do not slide.

If you try to push a heavy cart you may not be able to do so. If there are three or four boys to help you in starting the cart, then once it has started you will be able to move it alone without any help. It means that the sliding friction is slightly less than the static friction under the same conditions. From this we can conclude that static friction, *i.e.*, when bodies are at rest, is slightly more than that when they are in motion (sliding friction).

Measurement of frictional force is based on Newton's first law.

To measure the sliding frictional force of a wooden block along a board, we shall proceed as follows:

Let us place the block on a horizontal board and load it with a weight. Then let us move the block uniformly along the board with the help of a dynamometer (Fig. 1.17 *b*).

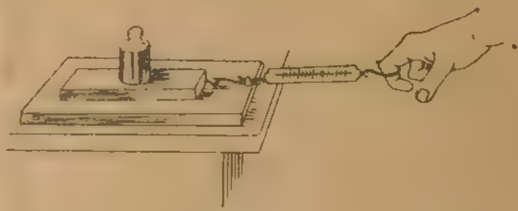


Fig. 1.17 (b). Finding the force of sliding friction

Here two forces are applied to the block.

(a) Pull—force applied by the hand, and

(b) Friction—the force appearing when one object moves along the surface of another, thus opposing the movement of the box and acting in the direction opposite to the pulling force (Fig. 1.17 *c*).

Fig. 1.17 (c). Forces acting upon the body which is in uniform motion

According to Newton's first law, a body (the block) can move uniformly and rectilinearly only if these two forces, *e.g.*, the force of pull and the force of friction are in equilibrium, *i.e.*, they are such forces which act upon one and the same body along a straight line in opposite directions and their magnitude is equal. So, it is concluded that **the force of sliding friction will be numerically equal to the pulling force.**

Force of friction=Pulling force. If we denote the force of friction by F, and the pulling force by P, we have in the case of uniform speed,

$$\boxed{F=P}$$

Consequently, we have a simple practical rule for measuring frictional force.

For measuring the force of friction it is necessary to bring an object in uniform motion and then the force of friction will be equal to the pulling force.

It is difficult to achieve in this experiment a strictly uniform movement of the block along the surface of the board through the hand-effort of the man. Therefore the precision measurement of frictional force depends on how close the created motion will be to uniform motion.

Just when the body is being brought out of the state of rest, the readings of the dynamometer will exceed those when the body is in uniform motion. This is accounted for by the fact that the initial readings of the dynamometer indicate the magnitude of the starting

frictional force which always exceeds the dynamic frictional force. In experiments, therefore, it is necessary to bring the body in uniform motion and to measure precisely with a dynamometer the force of pull under uniform motion.

Now take some wooden cylinders and place them on the table as shown in Fig. 1.18. The same

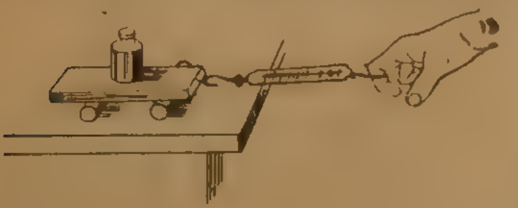


Fig. 1.18. Finding the force of rolling friction

wooden block is placed this time not on the table but on the wooden cylinders and is then pulled. You will find that the reading of the dynamometer is much less than before. The force now opposing the motion is rolling friction. This experiment proves that under the same conditions, the rolling friction is much less than sliding friction. Take a book and keep it on the table and hold its cover page in an inclined manner. Keep a pencil on the surface so that it is parallel to the width of the cover. Now push the pencil slightly by a finger. You will find that the pencil moves slightly. Let the same experiment be tried by keeping the pencil parallel to the length of the book. Now it is found that with a little push the pencil rolls much faster over the surface of the book.

These two examples show clearly that **under the same conditions, the sliding friction is much greater than the rolling friction.**

§ 10. Coefficient of Friction

Take three wooden blocks of equal weights and one wooden board. Let the surface of one of the wooden blocks be rough. Find out the weights of the wooden blocks. Suppose the weight of each block is 800 g wt. Determine the force of friction between the wooden block with a smooth surface and the wooden board by a dynamometer.

Let the value of this force be 240 g wt.

$$\frac{\text{Force of friction}}{\text{Weight}} = \frac{240 \text{ g wt.}}{800 \text{ g wt.}} = 0.3$$

Now put the second block on top of the first one and determine again the force of friction of the system. You will find that the force of friction becomes double in this

case and the dynamometer reads 480 g wt.

Therefore, $\frac{\text{Force of friction}}{\text{Weight}} = \frac{480 \text{ g wt.}}{1600 \text{ g wt.}} = 0.3.$

Put the third wooden block over the first two and find the force of friction. This will be equal to 720 g wt. Total weight of the 3 wooden blocks is=2400 g wt.

Therefore, $\frac{\text{Force of friction}}{\text{Weight}} = \frac{720 \text{ g wt.}}{2400 \text{ g wt.}} = 0.3.$

You have noticed by now that the ratio $\frac{\text{Force of friction}}{\text{Weight}}$ remains constant for the same pair of surfaces. This constant quantity is known as the coefficient of friction.

$$\boxed{\textbf{Coefficient of friction} = \frac{\textbf{Force of friction}}{\textbf{Weight}}}$$

So, if in the case of motion along a horizontal surface, F is the force of friction, P the weight of the moving body, and μ, the coefficient of friction, we have,

$$\boxed{\mu = \frac{F}{P}}$$

From this, the force of friction can be calculated by the relation,

$$\boxed{F = \mu \times P}$$

If the weight of the body changes, the frictional force also changes proportionately with the weight of the body. It means that if the weight of the body increases the force of friction also increases. If it decreases the force of friction also decreases proportionately. But there is no change in the value of the coefficient of friction. From these experiments, it is concluded that the coefficient of the friction does not depend upon the weight of the moving body. Let us conduct two more experiments. Take two blocks, one of wood and the other of metal. Let the two blocks be of equal weight and the sliding surfaces of the same smoothness. If we slide them over the same wooden board one after another, we find that the coefficient of friction in the two cases are not equal. It means that the coefficient of friction depends upon the kind of material of sliding body.

Again take two wooden blocks. The weights of both these blocks are equal but the sliding surface of one block is rough and that of another is smooth. If we slide them over the surface of the same wooden board one after another, we find that the coefficient of friction is not

equal in these two cases. It means that the coefficient of friction depends upon the quality of the sliding surfaces.

So from the above experiments, we finally conclude that coefficient of friction between two surfaces depends upon two factors: (i) the material of the surfaces concerned and (ii) the quality of the surfaces.

The following table gives the value of the coefficient of friction between different surfaces.

Wood on ice	0.035
Wood on wood	0.3 to 0.5
Steel on steel	0.17
Leather belt on iron	0.28
Rubber tyre on hard ground	0.4 to 0.6

We have seen that the force of friction acts in a direction opposite to that in which a body moves and acts parallel to the surfaces in contact. In order to displace a body from its position of rest a force has to be applied to overcome this force of resistance due to friction. A body cannot be moved along another surface unless a force is applied to the body to overcome the force of friction. From what has been stated above, one may think that the force of friction always creates difficulties because it offers resistance to motion. But it has some uses also. If there were no friction we would not have been able to walk on a muddy and slippery surface. It is the friction between the ground and our feet that helps us to move.

§ 11. Laboratory Work

Name: To determine the force of sliding friction by using a wooden block and kilogram weights.

Apparatus and Materials

Wooden board, wooden block with hooks, three equal weights of 100 g and dynamometer.

Procedure

1. Determine the weight of the wooden block.
2. Place the wooden block over the wooden board. Determine the force of friction by moving the block uniformly over the board with one, then two and finally three weights of 100 g each.
3. Enter your observations in the following table:

S. No.	*Weight of the block with weights*	*Force of friction*	*Force of friction / Weight*	*Coefficient of friction*	*Mean*

Exercise

1. The following results were obtained experimentally for coefficient of friction between pig-iron and wood. Find out the average value of the coefficient of friction.

Weight	*Force of friction*
2.0 kg wt.	1.0 kg wt.
3.0 kg wt.	1.4 kg wt.
4.0 kg wt.	1.9 kg wt.

2. The weight of a railway wagon is 2500 metric tons. If the coefficient of friction (rolling) is 0.003, what will be the force required to move the wagon uniformly ?
3. An engine having a force of 175 kg wt. can move a motor car uniformly on the road. Calculate the weight of the car if the coefficient of friction (rolling) is 0.04.

§ 12. Practical Applications of Friction

You have learnt now that friction has some useful applications also. When a moving car gets stuck in a muddy and slippery road and an attempt is made to drive the car, the wheels go on rotating but the car does not move. In this case, if some wooden plank is used or some grovel or sand is spread out on that slippery surface, only then the car can be moved. This process helps us to increase the friction between the surfaces (the tyres and the slippery ground). Perhaps you have also observed that rubber tyres used for motor cars and buses etc. have corrugated surfaces to increase the force of friction between the rubber tyres and the ground.

Rubber belts are used in different types of machines such as lathes in a workshop. Sometimes it is found that the belt goes on moving but slipping over the machines without rotating them. In these situations a type of paste is used on the rubber belt so that it does not slip.

How to minimize undesirable friction?

In some machines, different parts get damaged due to continuous friction. To minimize friction, oils are used for lubrication (Fig. 1.19). In such cases the frictional force can be reduced by lubrication to 1/8 or 1/10 of its original value.

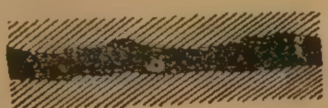


Fig. 1.19. Friction is reduced by lubrication

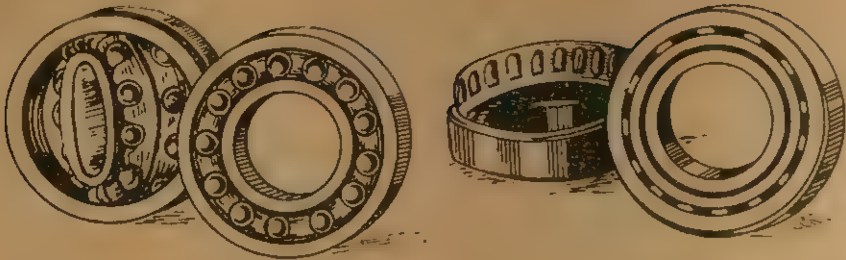


Fig. 1.20. (a) Ball bearing *(b) Roller bearing*

Sometimes ball bearings and roller bearings are used for reducing friction. These consist of small balls or rollers made of steel. Here the axle does not slide along the circle but rolls on the metal balls, or on the rollers. These bearings are lubricated by grease so that friction can be minimized to the maximum extent. Ball bearings and roller bearings used in different machines are shown in Fig. 1.20*a*, *b*.

Very often rollers are used in moving heavy objects with less effort. Fig. 1.21 shows three men trying to move a heavy block of wood by using some wooden rollers. Rolling friction is used in place of sliding friction because we have seen earlier that rolling friction is less than sliding friction. Thus heavy objects can be moved easily by using these wooden rollers.

Fig. 1.21. A heavy wooden block is moved with the help of rollers

Friction can be reduced to 1/20—1/30 of its original value by using ball bearings and roller bearings in motor cars, electric motors, cycles, etc.

Exercise

1. Study the working of ball bearings in a cycle in Fig. 1.22.

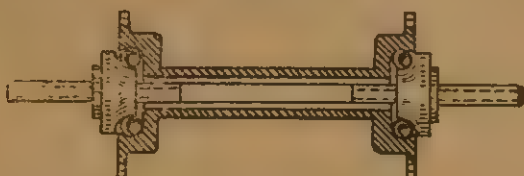
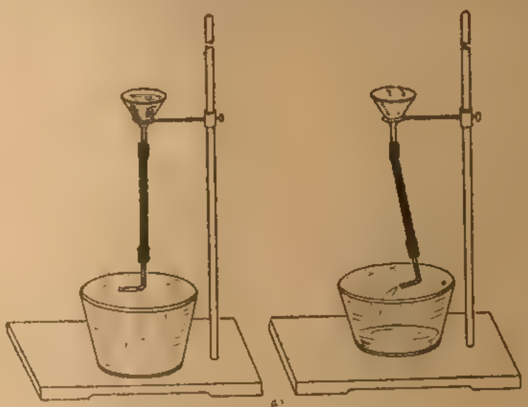


Fig. 1.22. Ball bearing in a cycle pedal

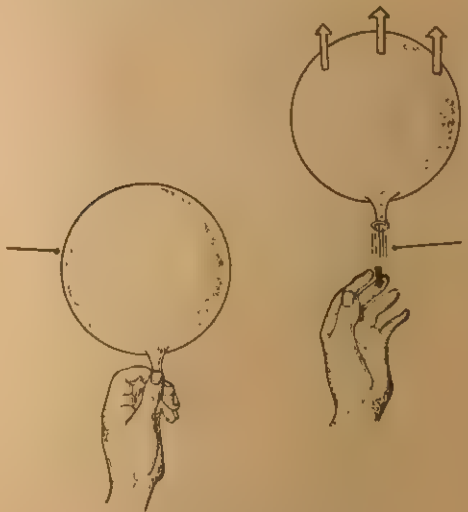
2. Carpenters usually put the screw into wax or grease first while fixing the screws into a board. Why?

§ 13. Action and Reaction

Let us make an arrangement as shown in Fig. 1.23*a*. Here, one glass funnel is fitted to one end and a glass tube bent at right angles to the other end of a rubber tube. The other end of the glass tube is closed with a cork. When the funnel and the tube are filled with water and the cork is taken out, the water flows out of the tube while the tube is pushed back in a direction opposite to the flow of water.



(*a*)



(*b*)

Fig. 1.23 (a). Water flowing out of the tube pushing it back in the opposite direction
Fig. 1.23 (b). The balloon moves in the opposite direction when air comes out

If we take a rubber balloon filled with air and leave the balloon, allowing the air to come out, we find that the balloon moves in the opposite direction. In this case the air inside the balloon while coming out exerts a force due to which the balloon moves in the opposite direction (Fig. 1.23*b*).

If a person wants to get down from a boat and jumps suddenly, the boat moves in the backward direction while the person moves forward. In jumping, the man exerts a force on the boat called action. The reaction due to the boat produces a force on the man which makes him move forward. But at the same time, the force due to the boat causes it to move backward. Fig. 1.24 shows a boy jumping from a boat.

Experiment

Take two dynamometers and keep them on the table. Hold the dynamometers in the way shown in Fig. 1.25 so that one dynamometer is attached to the hook of the other dynamometer

and pulled with a force. The readings indicated in the dynamometers will be the same. The second dynamometer is pulling the first one with a force while the first one exerts an equal but opposite force on the second one. This observation can be explained in the following way.

Fig. 1.24. A boy is jumping from a boat

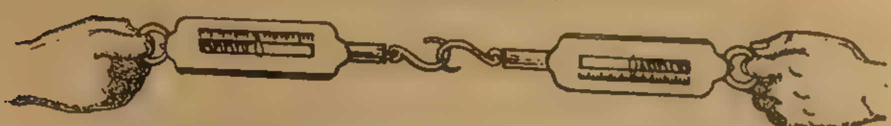


Fig. 1.25. Two dynamometers showing action and reaction

The force exerted by the second dynamometer on the first one can be called action, while the force exerted by the first on the second one can be called reaction. Thus we conclude that action and reaction are equal to one another but act in opposite directions. This fact was first stated by Newton. Perhaps you will be interested in knowing about Sir Isaac Newton, who was a

Fig. 1.26. Sir Isaac Newton

great scientist (Fig. 1.26). He enunciated the laws of motion that form the basis of mechanics. He was born in Great Britain in 1642 and died in 1727. He also studied the properties of light and also made some important contributions in the field of mathematics.

Exercise

1. What are the forces acting when a person walks? Mention which one is action and which one is reaction.
2. A book is kept on the table in Fig. 1.27. Explain the action and reaction in this case.

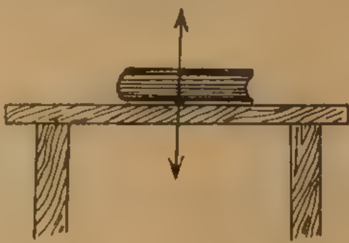


Fig. 1.27. A book is kept on the table

3. In a tug of war, two teams try to pull the rope from two sides. The rope remains stationary if the forces from two sides are exactly equal. Why?

Summary and Conclusions

1. Mechanical motion is the change in the position of a body with respect to another body.
2. All types of mechanical motion or the state of rest are relative.
3. A body may be in motion with respect to one body but the same body may be in the state of rest with respect to another body.
4. All mechanical motion can be classified from different points of view—

   (a) according to the trajectory—rectilinear and curvilinear.

(b) according to the speed of the body—uniform and non-uniform motion.

(c) according to the types of motion—translatory, rotatory and oscillatory motion.

5. If a body is in translatory motion, all points of the body describe similar trajectories and cover equal distances in the same interval of time.
6. A motion, in which a body covers equal distances in equal interval of time is called uniform motion.
7. A motion, in which a body covers unequal distances in equal interval of time, is called non-uniform motion.
8. Formulae for uniform and rectilinear motion:

$$V=\frac{S}{t}\ ;\ S=V\times t \text{ and } t=\frac{S}{V}$$

9. Formulae for non-uniform and rectilinear motion:

$$V_{av}=\frac{S}{t}\ ;\ S=V_{av}\times t \text{ and } t=\frac{S}{V_{av}}$$

10. The tendency of a body to remain in motion or at rest is called the inertia of the body.
11. All bodies in nature possess inertia. The magnitude of inertia depends upon the mass of the body, the greater the mass is, the greater will be the intertia.
12. Every body continues in its state of rest or uniform rectilinear motion unless a force acts upon it.
13. A body moves uniformly, if it is acted upon by balancing forces.
14. If a body changes the speed of its motion or its state of rest, it can be only under the action of a force.
15. The force which resists the motion of a body moving over another body and acts in opposite direction of the motion of the body is called the force of friction.
16. Friction is due to: (1) the roughness of the two surfaces in contact

    and (2) the interaction between the molecules of the two surfaces in contact.

17. There are three types of friction:

    (1) sliding friction
    (2) rolling friction and
    (3) static friction.

18. To measure the force of sliding friction, it is necessary to bring the body in uniform motion and then the force of friction is equal to the pulling force, i.e.,

    Force of friction = Pulling force

19. Sliding friction is greater than the rolling friction.
20. Coefficient of friction depends upon:

    (i) the type of the material and
    (ii) the roughness of the surfaces in contact.

    The coefficient of friction does not depend either on the weight or the surface areas of the bodies under contact.

21. The coefficient of friction in the case of horizontal surface is given by the formula,

$$\text{Coefficient of friction} = \frac{\text{Force of friction}}{\text{Weight of the moving body}}$$

or $\boxed{\mu = \dfrac{F_f}{P}}$ and $\boxed{F_f = \mu \times P}$

22. The action and reaction between two bodies are equal in magnitude but opposite in direction along the same straight line.

CHAPTER II

Composition of Forces, Equilibrium of Bodies

§ 14. Composition of Forces

From Newton's first law of motion you know that if a body either changes its speed of motion or its state of rest, it is only due to the action of a force acting upon the body. So the action of a force upon a body results in either the change of the speed of motion or its state of rest.

Now let us observe the effect of weight attached to the end of a suspended spring. After attaching the weight, there is an extension in the spring. This is due to the force of weight attached to the spring. So we see that another effect of a force is the deformation of the body upon which it is acting.

So we can conclude that the effect of a force may be either the change in the speed of motion or the deformation of the body acted upon by the force.

Each force is determined completely by three characteristics: (i) the magnitude, (ii) the direction and (iii) the point of application.

In physics, we often express a force in graphical form. It is expressed by a line with an arrow-head. The magnitude of the force is determined by the length of the line. The direction of the force is determined by the direction of the arrow and the point of application of the force by the point at the end of the line.

For example, if a force of 3 kg wt acts at a point in a body in a horizontal direction, it can be represented by an arrow-headed horizontal line of length 3 cm and drawn from the point of application of force in the body (Fig. 2.1). Here,

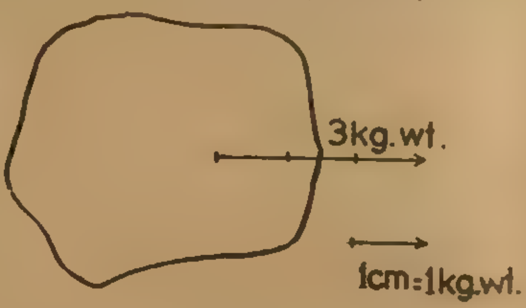


Fig. 2.1. Magnitude of force

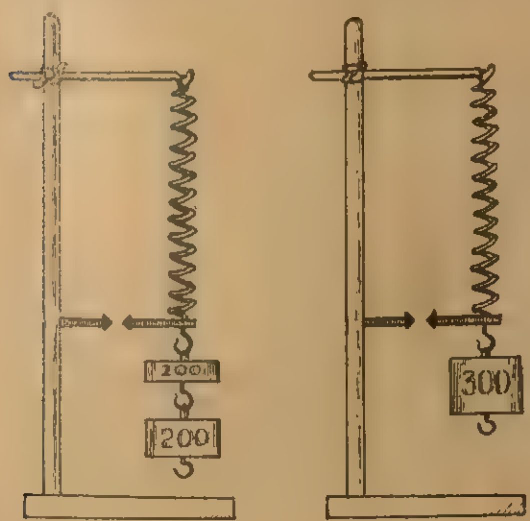
1 cm length of the line represents 1 kg wt of force.

Sometimes we find that there are several forces acting on a particular body. In these cases the same effect as produced by the several forces can be obtained by applying one force of proper magnitude and the process can be made much simpler.

For example, if the load is very heavy, one man cannot pull it by attaching a rope to it; but three or four people will be able to do so. You have often noticed that while moving a heavy cart, one man pulls it from the front and the other pushes it from behind. When a train moves up a hill, two engines are required; one at the front and the other at the rear. Assume that the first engine exerts a force of 14,000 kg wt on the train and the second engine pushes it forward with a force of 10,000 kg wt. The train is able to move up the hill due to the combined action of these two forces. If only one engine were to pull up the train, it must exert a force of 24,000 kg wt.

This force of 24,000 kg wt producing the same effect as the two forces of 14,000 kg wt and 10,000 kg wt acting in the same direction along a straight line, is known as the resultant force. The two forces 14,000 kg wt and 10,000 kg wt are known as the components.

Let us try to conduct an experiment as shown in Fig. 2.2(*a*). Two weights of 100 g and 200 g are suspended from a spring. These are then removed and replaced by a single weight so that the spring is extended up to the same length. You will find that the single weight required will be a weight of 300 g as shown in Fig. 2.2 (*b*).



(*a*) (*b*)

Fig. 2.2. Showing that equal forces stretch the spring equally. (a) the combined action of the two forces of 100 g w and 200 g wt (b) The action of the force of 300 g wt

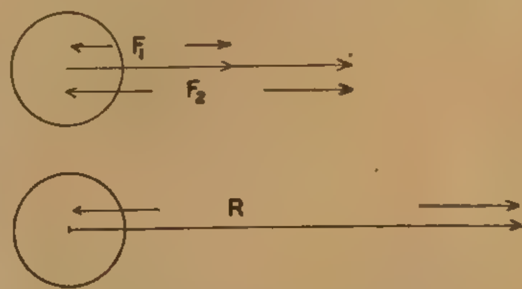


Fig. 2.3. The resultant of the two forces F_1, F_2 acting in the same direction is equal to their sum

The conclusion arrived at from the above experiment is that whatever the two weights may be, the total weight required to extend the spring to the same extent will be their sum. Fig. 2.3 shows that two forces F_1 and F_2 are acting in the same direction along a straight line. The resultant of these two forces is shown as R. In other words, **the resultant of two forces acting in the same direction along a straight line is *always* equal to the sum of these forces and acts in the same direction.**

If a rope is pulled by two boys from two ends, the rope moves in the direction of the greater force. For example, if one boy pulls it with a force of 10 kg wt and the other with 15 kg wt the value of the force which is effective in producing the motion of the rope towards the boy pulling it with 15 kg wt will be 5 kg wt.

In this case, the two forces 10 kg wt and 15 kg wt are called component forces and the force 5 kg wt is called the resultant.

From the above observations we can conclude that **the resultant of two forces acting in opposite directions along a straight line will be the difference between the two component forces. The resultant force will act in the direction of the greater force.** Try to do the following experiment to prove the above statement.

Experiment

Keep a weight of 500 g on the platform of a dynamometer as shown in Fig. 2.4 *(b)*. Attach another weight of 200 g to a string passing over a fixed pulley as shown in Fig. 2.4 *(c)*. The string is tied to the weights kept on the platform. You will find that the pointer of the dynamometer will indicate the force of 300 g wt. This force of 300 g wt is the difference between the two forces acting on the dynamometer. If instead of taking the weight of 200 g, 500 g is taken in the same experiment as shown in Fig. 2.4 *(d)* the pointer of the dynamometer will remain on zero of the scale. Can you give the reason why it happens like that ? The experiment shows that the two forces are acting in opposite directions along a straight line; one is pressing the platform with its weight while the other is pulling the weight kept on the platform in the upward direction with an equal force. The resultant of the equal forces acting in the opposite directions will be the difference between the two forces and will be equal to zero.

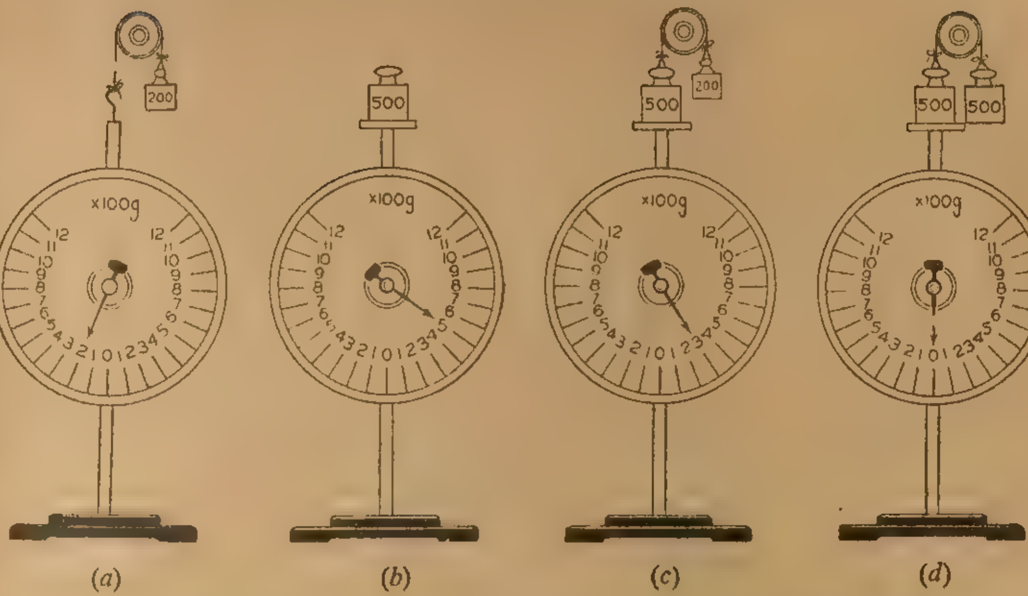


Fig. 2.4. Shows the principle of working of this type of dynamometer

(*a*) *If the force acts in the upward direction, the needle of the meter rotates clock-wise*

(*b*) *If the force is in the downward direction, the needle rotates in the anticlock-wise direction*

(*c*) *The resultant of the two forces acting in opposite directions*

(*d*) *The resultant of the two forces as indicated by the dynamometer is zero*

Two such component forces B_1 and B_2 acting in opposite directions are shown in Fig. 2.5. R is their resultant force and it acts in the direction of B_1.

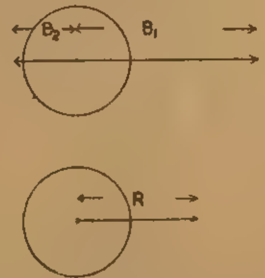


Fig. 2.5. The resultant of the two forces B_1 and B_2 acting in opposite directions is equal to the difference between them and is exerted in the direction indicated by the larger force

If two bullocks in a cart are unable to pull the cart due to the heavy load placed on it, sometimes a third bullock is used to make the cart move. Perhaps you have noticed that sometimes carriages are drawn by as many as six or eight horses. These are examples where several forces are acting on a body. We can now summarize from all these observations that a force which produces the same action on a body as several forces taken together is called the ***resultant force***.

Exercise

1. Two forces of the magnitude of 20 kg wt and 25 kg wt are acting in the same direction. Represent these forces pictorially.
2. Two forces of the magnitude of 15 newtons and 18 newtons are acting in opposite directions. Represent them pictorially.
3. Fig. 2.5 shows two forces B_1 and B_2 acting in opposite directions along a straight line. R is the resultant force and acting in the direction of the force B_1. Which one is the greater force, B_1 or B_2? Explain.
4. An object is floating on the surface of water. What are the forces acting upon the body? Find out the resultant force. Draw the diagram of these forces.
5. Fig. 2.6 shows a man coming down towards the earth *uniformly* with the help of a parachute. The weight of the man together with the parachute is 70 kg wt. Calculate the force exerted in the upward direction by the air.

Fig. 2.6. A man coming down towards the earth with the help of a parachute

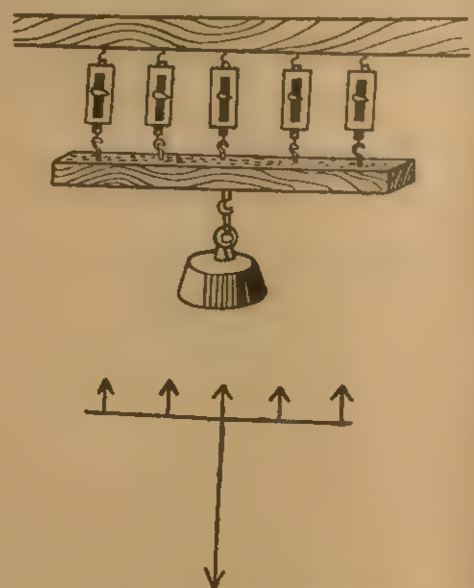


Fig. 2.7. Five similar dynamometers kept suspended from a fixed support

6. A body weighing 25 kg wt is completely immersed in water without touching the bottom. The volume of the body is 3 cu dm. Calculate the force that would keep it in the same position.

7. Fig. 2.7 shows 5 similar dynamometers kept suspended from a fixed support. The lower ends are connected to a movable rod. A 2 kg wt is suspended from the middle of the lower rod. Give the readings of the dynamometers.

§ 15. Centre of Gravity

If you throw a stone in the air, it falls to the ground. This is because the earth attracts all bodies towards itself. This law was first formulated by Newton.

A body consists of a large number of material particles held together as shown in Fig. 2.7(*a*). Each particle of the body will be attracted towards the centre of the earth with a force proportional to its mass. The distance of these particles from the centre of the earth is so great that these forces will be parallel to each other. The resultant of all these parallel forces (R) will be equal to the weight of the body (P), i.e., the sum of the weights of each part of the body taken separately. The point of application of this resultant force is known as the centre of gravity of the body. We may try to keep the body in any position but this point, through which the resultant force passes, will always remain the same.

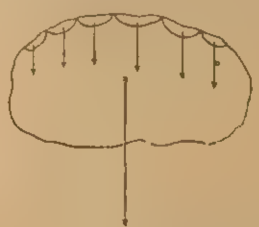


Fig. 2.7(a). The resultant of the parallel forces are equal to the weight of the body

Try to understand the centre of gravity by performing the following experiments. Take some pieces of cardboard; some are of symmetrical shapes such as a rectangle, a circle and a triangle; and others are of unsymmetrical shapes. Try to find out their centres of gravity.

Experiment

1. Take a rectangular piece of cardboard and find out the point of intersection of its diagonals. Try to balance the cardboard by a pencil, so that it remains stationary when balanced at the tip of the pencil as shown in Fig. 2.8(*a*). You will find that it is possible only when the tip of the pencil is held against the point of intersection of the diagonals.

   In the above case, the body is in equilibrium because two balancing forces are acting upon the body. Here, the weight of the body and the reaction of the pencil constitute the balancing forces.

2. Take a circular piece of cardboard. Find out its centre. Try to balance the cardboard by holding it at the tip of the pencil as shown in Fig. 2.8(*b*). You will find that it will remain stationary only when the tip of the pencil is placed exactly at the centre of the circle.

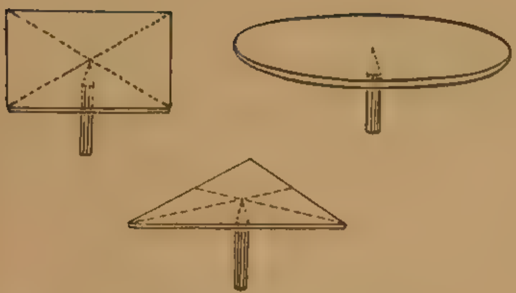


Fig. 2.8. (a) A rectangular piece of cardboard is balanced on a pencil
(b) A circular piece of cardboard is balanced on a pencil
(c) A triangular piece of cardboard is balanced on a pencil

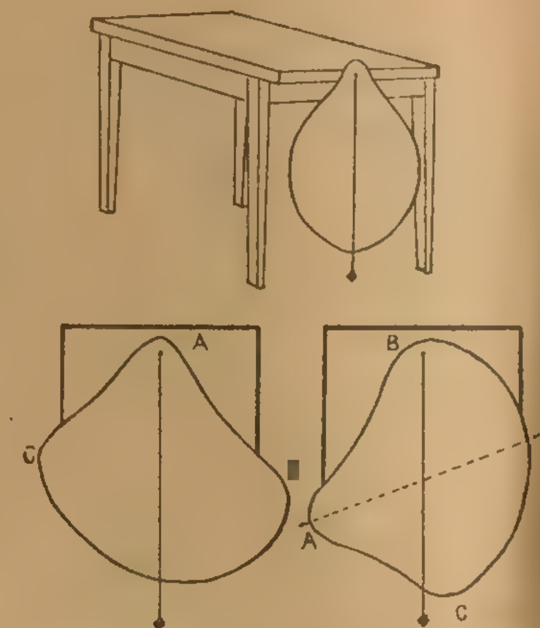


Fig. 2.9. Finding the centre of gravity of cardboards of irregular shape

3. Take a triangular piece of cardboard. Join each vertex with the middle point of the opposite side. Try to balance the cardboard so that the tip of the pencil is at the point of intersection as shown in Fig. 2.8(*c*).

4. Take a piece of cardboard of an irregular shape. Hang it on the side of a table by a pin. Use a load attached to a string hung from the pin as a plumb line. Draw a line coinciding with the plumb line as shown in Fig. 2.9. Hang the same cardboard in different positions, and using the plumb line, draw vertical lines in each case.

   Find out the point of intersection of all these vertical lines. This point of intersection will be the centre of gravity of the cardboard.

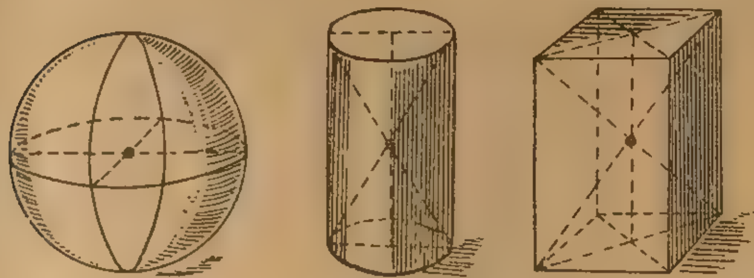


Fig. 2.10. The position of centre of gravity in (a) a sphere, (b) a cylinder, (c) a 6-sided prism

From the above experiments we find that, whether a body is symmetrical or unsymmetrical, there is a fixed point such that if it is balanced at that particular point it remains stationary. In other words, if a body is *balanced* at this point, it will remain at rest.

Fig. 2.10 shows the centre of gravity of some solid bodies (symmetrical) such as a sphere, a cylinder and a 6-sided prism. The centre of gravity of a uniform sphere is always at its centre, for a uniform cylinder it is at the middle of the line that connects the centres of its bases.

Experiment

Take a piece of cardboard (unsymmetrical) as mentioned in the earlier experiment and try to balance it at the tip of a pencil holding it at its centre of gravity. If the same thing is tried for

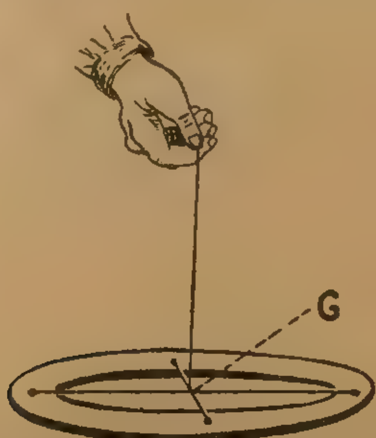


Fig. 2.11. The centre of gravity of a circular ring

various positions of the cardboard, you will find that, whatever may be the positions of the body, the position of its centre of gravity always remains the same.

Take a big circular ring. Fix two threads as shown in Fig. 2.11. Find out the point of intersection of its diameters. When suspended from this point, the ring remains horizontal. This experiment shows that the centre of gravity may even lie outside the body.

§ 16. Laboratory Work

To find out the centre of gravity of some flat objects.

Apparatus and Materials

Symmetrical and unsymmetrical pieces of cardboard, thread, pin and a plumb line.

Procedure

Find out the centre of gravity of the different pieces of the objects on a pivot. The cardboards should remain horizontal.

Find out geometrically the centre of gravity of a circular disc and of triangular and rectangular cardboards. Try to verify experimentally the results obtained.

§ 17. Equilibrium of Bodies

The effect of forces on a body actually determines whether the body will remain at rest or will move. When bodies remain stationary we express it by saying that they are in equilibrium.

The body remains in equilibrium if the resultant force on the body is zero.

Let us take a half metre scale and fix it by a nail, so that it remains vertical when freely suspended. Now try to displace the scale slightly. The moment you remove your finger, you will find that it comes back to its original position. This condition of a body, in which a body when displaced slightly from its position of rest returns to its original position, is known as *stable equilibrium.*

You will find from Fig. 2.12 that the centre of gravity G of the scale lies exactly on the vertical line passing through the point of suspension. When the scale is displaced from the position of stable equilibrium, its centre of gravity moves higher. When the body is allowed to move freely, the centre of gravity

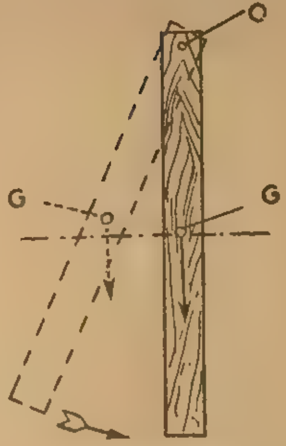


Fig. 2.12. Stable equilibrium of a scale

G comes back to the lowest position.

If you balance the scale on your finger-tip as shown in Fig. 2.13 and make a slight movement, then

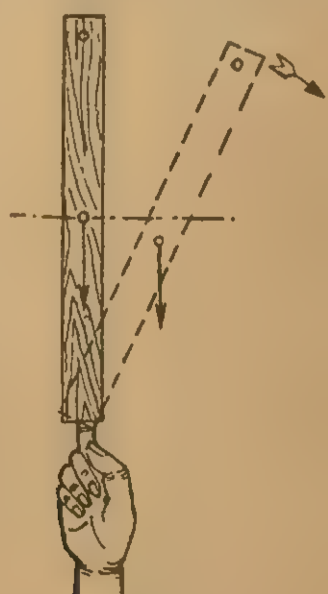


Fig. 2.13. Unstable equilibrium of a scale

the scale will fall from your hand. This particular position, in which a body when slightly displaced from its equilibrium position does not return to its original position, is known as *unstable equilibrium.* From Fig. 2.13 you can see that in unstable equilibrium the centre of gravity is lowered when the body is slightly displaced.

Next try to fix the scale so that the point of suspension and the centre of gravity coincide as shown in Fig. 2.14. Now you will find that the centre of gravity will always occupy the same position in whichever way the scale is placed.

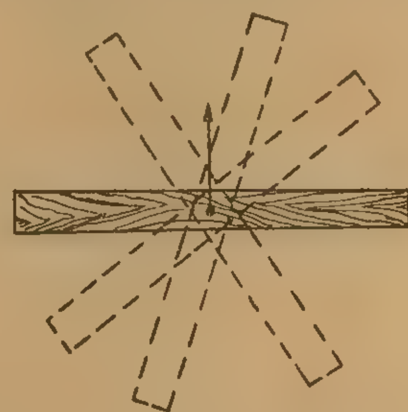


Fig. 2.14. Neutral equilibrium of a scale

This particular condition, in which the centre of gravity of the body occupies the same position when the body is displaced slightly, is known as the *neutral equilibrium.*

The three conditions of equilibrium, stable, unstable and neutral, are shown in Fig. 2.15. An ordinary marble when kept on a concave surface will always remain in equilibrium (stable). On the other

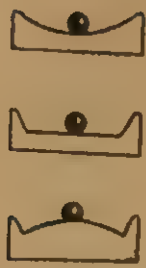


Fig. 2.15. A marble in different states of equilibrium

hand, if it is kept on a horizontal surface, it will remain in neutral equilibrium. It is extremely difficult to keep a marble on a convex surface. This illustrates the state of unstable equilibrium.

In some plastic toys a small piece of lead is attached to the bottom, so that the bottom becomes heavy. If the toy is displaced slightly from its position of rest it comes back quickly to its original position. As the bottom is heavy, the centre of gravity in this case is raised slightly when the toy is slightly displaced. Fig. 2.16 shows a toy in two positions : (*a*) when it is at rest, (*b*) when it is slightly displaced. It also shows some toys where the centre of gravity is brought below the point of support.

(*a*) (*b*)

Fig. 2.16. Some toys where the centre of gravity is brought below the point of support

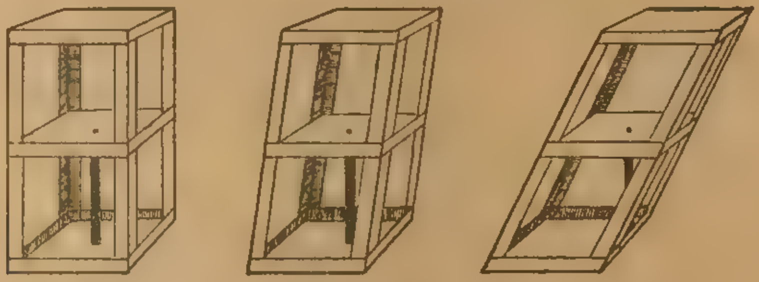
Practical examples of neutral equilibrium are found in some machines such as pulleys where the axis of rotation passes through the centre of gravity.

We have discussed particular cases of equilibrium when an object (scale) moves about a fixed point which acts as a pivot. In practice, we come across various cases where the object rests on a surface. The conditions of equilibrium of these objects can be understood clearly by performing certain experiments.

Experiment

Take a two-storey cage as shown in Fig. 2.17(*a*). The centre of gravity is always at the centre of the middle surface. A plumb line is suspended from this point. The four vertical strips supporting the three surfaces are made in such a way that their positions can be altered.

The inclination of the cage can be changed in this way. The position of the plumb line, as the inclination is gradually changed, is kept under observation (Fig. 2.17*b*).



(*a*) (*b*) (*c*)

Fig. 2.17. A two-storey cage with inclined base and plumb line

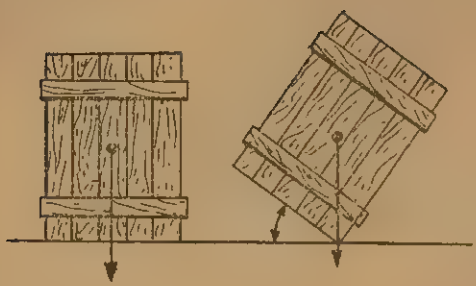
From these observations you will find that the cage is in stable equilibrium, so long as the plumb line remains within the base. Fig. 2.17(*c*) shows that when the inclination increases more and more, the plumb line ultimately lies just along the edge of the base. If the inclination is increased further, the whole cage topples down. Thus we can conclude that when a body rests on a surface, the position of the plumb line suspended from the centre of gravity determines whether the body will be in stable equilibrium or not.

When the vertical line passing through the centre of gravity remains within the base of the body, it is always in stable equilibrium. If it falls outside the base, the body becomes unstable. We find that an object resting on a surface can be made more stable by increasing the area of the base.

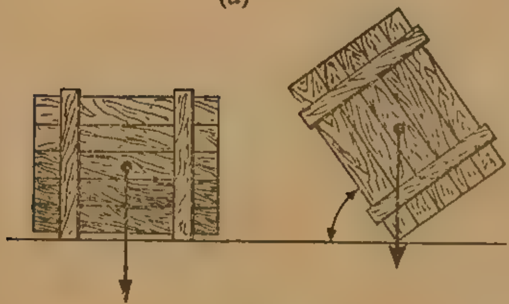
Have you ever noticed that, in a circus, a person, while walking on the rope, tries to keep balance by holding an umbrella or a stick in his hands? If you are carrying a load in one hand you have to bend yourself in the opposite direction. But if you are carrying equal loads in each hand, then you can walk straight instead of bending yourself.

Fig. 2.18(*a*) shows a packing box kept in a particular way so that it is in stable equilibrium. If we try to tilt the box more and more the angle gradually increases. The vertical line passing through the centre of gravity ultimately passes through one corner.

Fig. 2.18(*b*) shows that the same packing box becomes more stable if the wider surface is used as the base. In order to make it unstable the box has now to be tilted through a greater angle. The angle is thus much more in the second case. In a balance used in school, the base is



(*a*)



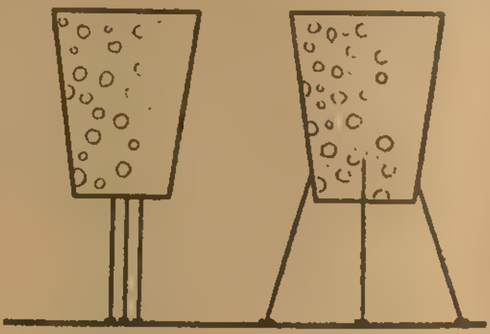
(*b*)

Fig. 2.18. Showing that stability increases with the area of the base

It is more difficult to turn a heavy packing box with a larger base. The same box can be turned more easily by using the smaller side as a base.

There are some examples where a body does not rest on a base but at several points, such as a table resting on four legs, a camera-stand forming a triangular area at the base.

A cork is kept on the table by sticking three pins close together as in Fig. 2.19(*a*). A slight push displaces the cork. If the pins are



(*a*) (*b*)

Fig. 2.19. A cork is balanced on the two different bases

attached the way it is shown in Fig. 2.19(*b*) making the area of the base wider, you will find that the cork is more stable.

made heavier and wider to make it stable.

We can summarize the above observations by saying that an object can be made more stable by either increasing the area of the base, or by lowering the centre of gravity. This can be achieved by making the base heavier. Sometimes these things can be done simultaneously.

Exercise

1. The tongawalla never allows more passengers to sit either in the front seat or in the back one. Why?
2. Why do the ducks have a swaying motion?

3. If three similar trucks carry the same weights of iron rods, bricks and logs of wood, which one do you think will have the greatest stability?
4. If one has to arrange some heavily packed boxes along with some empty boxes on a truck for transport from one place to another, how should it be done?
5. A truck is taking a bend, its centre of gravity G is shown in Fig. 2.20. Do you think it will topple?

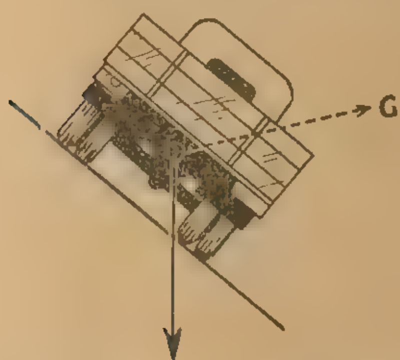


Fig. 2.20. A truck is taking a bend, its centre of gravity is shown by G

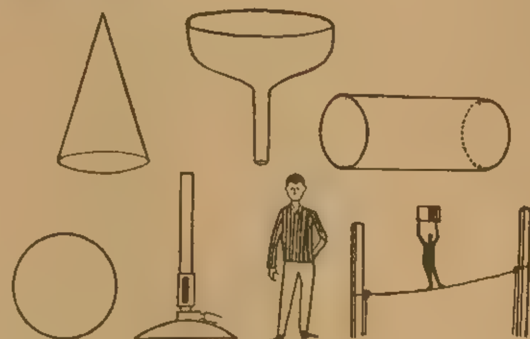


Fig. 2.21. Different states of equilibrium of some objects

6. Why the utensils that are generally used have a circular base?
7. A truck gets unbalanced very easily on an uneven road, while a motor car does not. Why?
8. Some pictures are shown in Fig. 2.21. Mention the states of equilibrium of the different objects. Enter your observations in the following table and explain briefly.

Fig.	*Stable or Unstable Equilibrium*	*Explanation in brief*
A		
B		
C		
D		
E		
F		
G		

Summary and Conclusions

1. Force is the cause for either change in the speed of the body or any deformation in its shape or size.
2. If a body has non-uniform motion, there is a force acting upon the body.
3. If a body is deformed, it is only due to the action of a force.
4. Each force is completely determined by three things:

   (1) the magnitude, (2) the direction and (3) the point of application of the force.
5. All effects of a force depend upon the above three characteristics of the force.

   If any one of them is changed, the effect of the force is also changed.
6. A force can be completely expressed in graphical form with the help of a line with an arrow-head. The length of the line determines the magnitude, the direction of the arrow determines the direction and the end point of the line determines the point of application of the force.
7. Composition of several forces results in a single force which has the same effect as those of the several forces acting upon the same body.
8. The single force, which produces the same effect as those of the several forces combined together, is known as resultant force.
9. The resultant of two forces acting in the same direction along a straight line is equal to the sum of the magnitudes of those two forces and acts in the same direction.
10. The resultant of two forces acting in opposite directions along a straight line is equal to the difference of the magnitudes of those two component forces. The resultant force acts in the direction of the greater force.
11. The resultant of two balancing forces is equal to zero.
12. Centre of gravity of a body is the point of application of the resultant force of all the weights of different parts of the body.

13. A body is in equilibrium if the resultant of all the forces acting upon the body is zero.
14. There are three types of equilibrium of bodies capable of rotating about an axis:
    (a) *Stable equilibrium*—A body is in stable equilibrium if its centre of gravity is below the axis of rotation.
    (b) *Unstable equilibrium*—A body is in unstable equilibrium if its centre of gravity is above the axis of rotation.
    (c) *Neutral equilibrium*—A body is in neutral equilibrium if its centre of gravity is at the axis of rotation.
15. Stability of a body at rest depends upon (i) the area of the base and (ii) the height of the body.

CHAPTER III

Work and Energy

§ 18. Mechanical Work

We are quite familiar with the word 'work'. It brings to our minds the idea that something is being done. Perhaps you know that in cricket we use the word 'run'. It is an ordinary word but it has a special meaning in cricket. Similarly, the word 'work' has a special meaning in science. When we say that a man is carrying some bricks from one place to another, we mean the physical work done by the man. A teacher while giving some lessons to a student does not do any physical work but in the process of thinking and doing something he does mental work.

If you lift a heavy parcel from the floor and keep it on the table, you do some amount of work. The earth pulls the parcel downwards, and the force of your arms overcomes this pull in the downward direction. Suppose you are asked to hold the same parcel for several minutes so that it remains stationary in the same position. Here the force of your arms supports the weight but does not lift it. Scientifically, you have not done any work.

In physics, work is done when a force overcomes a resistance and moves the object on which it acts.

There are several kinds of resistances which a force can overcome. The weight of an object is a common kind of resistance. We overcome this resistance whenever we lift an object. Work is done when we lift water from a well, when a man climbs a mountain and when an aeroplane takes off in the air.

You now know what force of friction is. Work is done when you do something to overcome the force of friction. In a bicycle, if you wish to keep the wheels turning, you apply a force to overcome friction. Sometimes, we use tools for cutting wood, bending bars, and making holes. There, the purpose is to change the size or shape of an object and in overcoming the resistance, we do work.

When we stretch a spring, lift a piece of stone or use a pump for pressing air into a bicycle tube, we do work. These types of physical work are called mechanical work.

Mechanical work is done if the following two conditions are fulfilled. (i) A force must act upon a body and (ii) the body must move under the action of the force.

§ 19. Work and its Units

Let us assume that a weight of 1 kg is lifted through a height of one metre. One has to exert a force of 1 kg wt. To lift a weight of 5 kg uniformly through the same height one has to apply a force which is five times greater than the first one and the work needed is five times more.

Similarly if the same weight of 1 kg is lifted through three metres, the work done will be three times the work needed to lift it through one metre only.

The statements given above can be summarized as follows: **The amount of mechanical work done is proportional to the magnitude of the force applied and the distance through which the body moves under the action of the force, *i.e.*, the displacement.**

$$\boxed{\textbf{work done} = \textbf{force} \times \textbf{displacement}}$$

If we represent the work done by W, the force by F and the displacement by S, then

$$\boxed{\mathbf{W = F \times S}}$$

When force is expressed in kgwt and the distance in metre, the work is measured in kgwtm.

$$\boxed{\textbf{1 kgwtm} = \textbf{1 kgwt} \times \textbf{1 metre}}$$

Again, there is another unit of force known as *newton*. It is denoted by the symbol N, and is related with the unit of kgwt by the relation,

$$9.8 \text{ N} = 1 \text{ kgwt}$$

Therefore, if force is expressed in newton and the distance in metre, another unit of work known as *joule* is obtained.

$$\boxed{\textbf{1 joule} = \textbf{1 newton} \times \textbf{1 metre}}$$

So the unit of kgwtm and joule is related by the relation,

$$\boxed{\textbf{1 kgwtm} = \textbf{9.8 joules}}$$

If we want to lift a weight of 10 kg from the floor to the rack at a height of 2 metres, work done $= 10$ kgwt $\times 2$ metres $= 20$ kgwtm.

Exercise

1. A wooden block is pulled by a dynamometer over a flat surface through a distance of 60 cm. The force applied is read directly from the dynamometer. The needle of the dynamometer is on the third division. One division of the dynamometer reads a force of 50 gwt (Fig. 3.1). Calculate the work done.

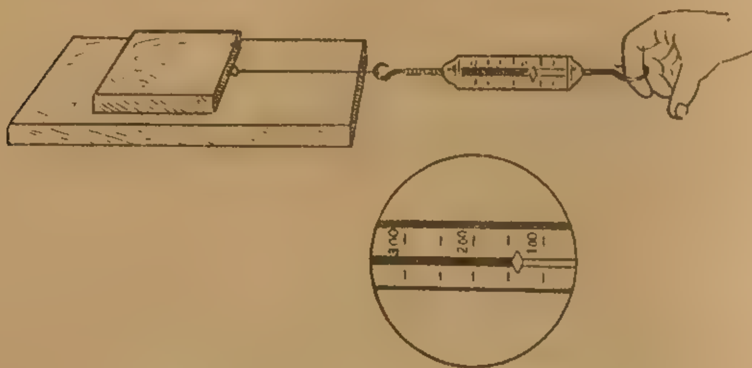


Fig. 3.1. A wooden block being pulled by a dynamometer over a flat surface. The dynamometer is shown below on a magnified scale

2. Calculate the work done when a weight of 500 kg is raised through a height of 50 metres.
3. Calculate the amount of work done in lifting a block of granite through a height of 100 metres. The volume of the block is $5m^3$ and its density is 2.5×10^3 kg/m^3.

Fig. 3.2. The body is lifted and lowered when a person walks

4. A man lifts a weight through a height of one metre, and the same weight is pushed across a table for a distance of one metre. Do you think that the work done will be same in both the cases?

5. The work done in walking is mainly due to the body being lifted regularly. In every step the body is lifted and then lowered by 6 cm. Calculate the work done by a man weighing 45 kg, if his steps are 60 cm and he walks through a distance of one kilometre (Fig. 3.2.).

§ 20. Power

We have seen that the work done is measured by the product of force applied to a body and the distance through which the body moves. But from common experience we know that if the same work is done by different methods, time taken will be different. For example, a labourer will take much more time in carrying bricks and other building materials to a height than a crane used for the same purpose.

A plot of land, when ploughed in an ordinary way, will take much more time, compared to the time taken by a tractor to plough the same plot of land. When we think of doing a piece of work much faster, it gives us the idea of calculating the amount of work done in unit time. This quantity is called power; it is defined as the rate of doing work.

$$\boxed{\text{Power} = \frac{\text{Work done}}{\text{Time taken}}}$$

Let us assume that W is the amount of work done in time t.

Then work done in unit time, i.e., the power P is given by

$$\boxed{P = \frac{W}{t}}$$

If the work done is expressed in kgwtm and the time in second, the power is measured in the unit of $\frac{kgwtm}{sec}$.

$$\boxed{\frac{1\ \text{kgwtm}}{\text{sec}} = \frac{1\ \text{kgwtm}}{1\ \text{sec}}}$$

If the work done is expressed in joule, the power is measured in *watt*. Thus,

$$\boxed{1\ \text{watt} = \frac{1\ \text{joule}}{\text{sec}} = \frac{1}{9.8}\ \frac{\text{kgwtm}}{\text{sec}} = 0.102\ \frac{\text{kgwtm}}{\text{sec}}}$$

As watt is a very small unit of power, kilowatt is generally used for measuring the power, where,

1 kilowatt = 1000 watts

we also use another unit of power, known as *horse power* (HP), where,

$$\boxed{1\ \text{HP} = 76\ \frac{\text{kgwtm}}{\text{sec}}}$$

The following table gives you an idea of the power of different machines as compared to that of a man.

Man 0.037 kW—0.075 kW (0.05 HP—0.10 HP)

Horse . . . . . 0.30 kW—0.45 kW (0.4 HP—0.6 HP)

Motor car engine 5.8 kW—23 kW (8 HP—32 HP)

Tractor engine . . . . 70 kW (93 HP)

Steam engine . . . . . 2,200 kW (3,000 HP)

Diesel locomotive . . . . 2,950 kW (4,000 HP)

Electric locomotive . . . . . 4,100 kW (5,600 HP)

The work *W* done by any machine in a definite interval of time *t* can be calculated by the product of the power of the engine and the time *t* taken by it.

$$\boxed{W = P \times t}$$

Example:

If the power of an engine of a heavy truck is 90 HP, calculate the work done by the engine during one minute.

$P = 90$ HP
$t = 1$ mt.
W—?

$$\begin{aligned} W &= P \times t \\ &= 90\ \text{HP} \times 1\ \text{mt.} \\ &= 90 \times 76 \frac{\text{kgwtm}}{\text{sec}} \times 60\ \text{sec} \\ &= 410400\ \text{kgwtm} \end{aligned}$$

There is another way of calculating the power of the machine if its uniform speed is given as follows:

$$P = \frac{W}{t} \text{ and } W = F \times S$$

$$\text{Hence } P = \frac{F \times S}{t} = F \times \frac{S}{t}$$

$$\text{As, } \frac{S}{t} = V \ldots\ldots \text{ where V is the uniform speed}$$

$$\boxed{\therefore\ P = F \times V}$$

If the speed is non-uniform, the average power P_{av} is given by the relation

$$\boxed{P_{av} = F \times V_{av}}$$

where V_{av} is the average speed of non-uniform motion.

Example:

If a tractor develops a force of 1000 kgwt and moves with a uniform speed of 2 metres per second, calculate its power.

$F = 1000$ kgwt
$V = 2 \frac{\text{m}}{\text{sec}}$
P—?

$$\begin{aligned} P &= F \times V \\ &= 1000\ \text{kgwt} \times 2 \frac{\text{m}}{\text{sec}} \\ &= 1000 \times 2\ \text{kgwt} \frac{\text{m}}{\text{sec}} \\ &= 2000 \frac{\text{kgwtm}}{\text{sec}} \end{aligned}$$

The example given above explains clearly why the speed of a motor increases with the power of the engine. For the same power of engine, changing the speed helps in producing the necessary change in force exerted by the engine. Perhaps you have noticed that while climbing up the slope, the driver reduces the speed and changes the gears accordingly.

Exercise

1. Calculate the work done by a 10 kw motor in 20 minutes.
2. The weight of a boy is 20 kg. If he moves up the stairs 10 metres high in 20 seconds, calculate his power and express it in terms of HP.
3. A diesel locomotive having a power of 3000 HP can exert a force of 18,000 kg wt. Calculate the time taken by it to cover a distance of 500 metres.
4. Assume that a person walks on a horizontal surface, and covers 10,000 paces in two hours, and does 4 kg wt/m of work in each step. Calculate his power.

§ 21. Simple Machines

Levers

You have learnt earlier what is 'work' and how it can be measured. You have also seen that sometimes machines are used for doing some work more quickly.

We usually think of a machine as an assembly of complicated parts properly designed and fitted together to do some special types of work. When we examine the individual parts of such a machine, we may be surprised to find that it is built up on the principles of some simple devices used over and over again. Some of these simple devices are:

(a) Lever
(b) Wheel and axle
(c) Pulley
(d) Inclined plane

You will learn about the complicated machines in detail later on. We shall confine ourselves here to these simple devices. Lever is one of the first machines ever used by man and it is the simplest form of a

Fig. 3.3. A man is exerting a force at one end of the rod by pressing it downwards

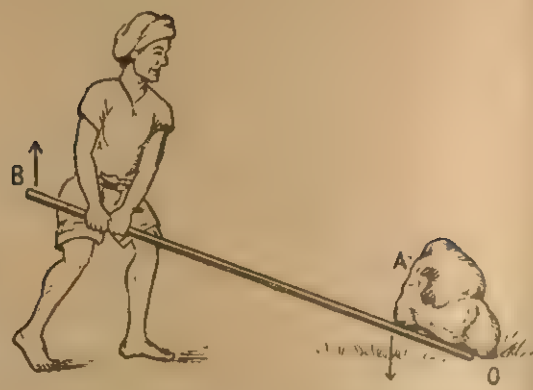


Fig. 3.4. A man is exerting a force in the upward direction in an attempt to raise the load

machine. It consists of a rigid bar turning about a fixed point known as the **fulcrum.**

Fig. 3.3 shows a man exerting a force at one end of the rod by pressing it downwards.

The forces acting on a lever can turn it around its axis in two directions : clockwise and anti-clockwise. Fig. 3.4 shows a man exerting a force in the upward direction in an attempt to raise the load. If you study the position of the fulcrum in the pictures given above you will find that in the first one, two forces *A* and *B* act in the same direction and the fulcrum *O* is in between them. In the second one, the forces *A* and *B* are acting in the opposite directions.

The distance between the point of application of the force and the fulcrum is known as the **lever-arm.**

§ 22. Moment of a Force

The turning effect of a force depends on how large the force is, and also on how far the force is from the fulcrum, *i.e.*, the point about which it is turning.

In effect the arm of the lever is measured as the perpendicular distance between the fulcrum and the line of action of the force.

This effect of the force which produces a rotatory motion is called the moment of the force. This moment is equal to the product of the force and the arm of the lever. If we denote the moment of the force by M, the force by F and the arm of the lever by l, we have,

$$\boxed{\mathbf{M}=\mathbf{F}\times l}$$

Have you ever observed carefully

the opening of a door, when it is turned about a hinge at one end? If the point of application of the force is very near to the hinge, one has to apply a greater force. On the other hand, one has to push it slightly if the point is at a large distance from the hinge.

Equilibrium of forces on a lever

You have seen that a lever is used for lifting a weight in a convenient way and this is achieved by exerting a force at a definite distance from the fulcrum *O* to overcome the weight of the body.

If we take a straight rod which can turn about a fixed point and try to do some experiments by attaching fixed weights to it, the result of the experiment will show that to keep the rod horizontal we have to use particular values of weights for different distances from the fulcrum.

For example, Fig. 3.5 shows that a force of 200 g wt acts on a lever-arm of 20 cm to keep the lever in equilibrium (*i.e.*, horizontal) and a force of 100 g wt is required to be placed at a distance of 40 cm on the opposite side of the fulcrum.

If the same weight of 200 g wt is kept at a distance of 10 cm, the force required to keep the rod in equilibrium is 50 g wt at the end of the lever-arm of 40 cm.

When the experiment is repeated with a weight of 50 g wt at a distance of 30 cm from the fixed point,

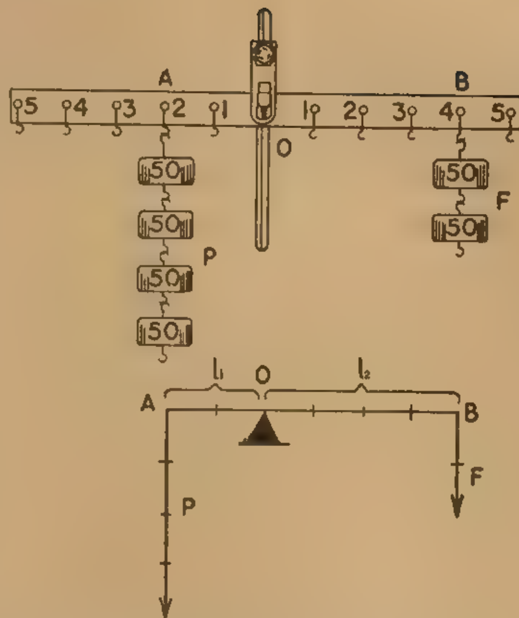


Fig. 3.5. The equilibrium of a lever with its fulcrum O between the acting forces: 0A—arm of the force P, 0B—arm of the force F

i.e., the fulcrum *O*, it is found that a weight of 150 g wt should be placed at a distance of 10 cm from the fulcrum on the other side to keep the lever in equilibrium.

The results of the above experiment show that the lever is in equilibrium (*i.e.*, the rod remains horizontal) under the action of two forces. If one of the forces is half the value of the other one, then its lever arm has to be doubled. When one of the forces is 1/4th of the other force, its lever arm should be increased 4 times, and so on.

The results of the above experiment are given in the following table.

Force rotating the lever anti-clockwise		Force × lever arm	Force rotating the lever clockwise		Force × lever arm
Force in g wt	lever arm in cm	Moment g wt × cm	Force in g wt	Lever arm in cm	g wt × cm (Moment)
200	20	4,000	100	40	4,000
200	10	2,000	50	40	2,000
50	30	1,500	150	10	1,500

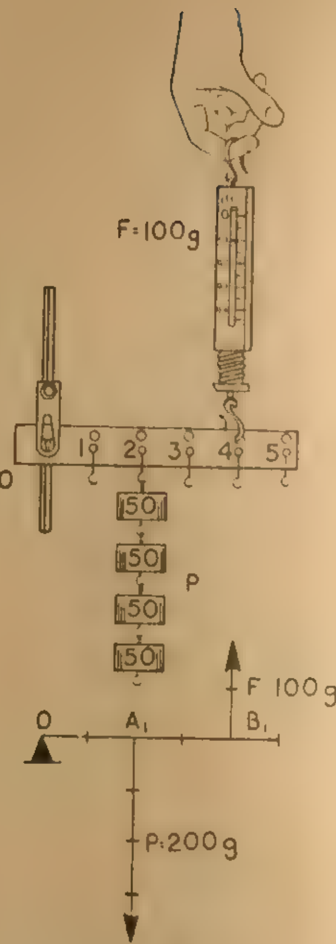


Fig. 3.6. The equilibrium of a lever with forces A and B, on the same side of the fulcrum O

It is evident from the above results that the moment of the force in the clockwise direction is counterbalanced by the moment of the forces in the anti-clockwise direction, when the lever is in equilibrium.

Similar experiments can be done by making an arrangement shown in Fig. 3.6 where the fulcrum is at one end of the lever and the two forces are in opposite directions.

If the two forces are represented by P and F and the corresponding lever arms are l_1 and l_2 respectively, then for equilibrium (Fig. 3.5),

$$P \times l_1 = F \times l_2$$

You may think that this principle is only applicable to a straight rod shown as a lever. But it is not so. This rule can be applied for any kind of lever, provided you remember that the lever-arm is the perpendicular distance between the

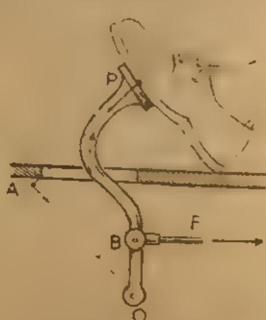


Fig. 3.7. The brake pedal of a motor car

fulcrum and the point of application of the force.

When a force is applied on the brake pedal of a motor car (Fig. 3.7), the two arms are OA and OB respectively. The force applied on the brake is shown as P. One has to draw the line PA for dropping the perpendicular from the fulcrum O. The force F is acting at the point B so that OB is the corresponding lever arm.

Exercise

1. Find out the weight necessary for placing at a distance of 15 cm from the fulcrum to balance a weight of 75 g wt placed at a distance of 12 cm.
2. Explain by diagram, the application of the moment of force in a seesaw.

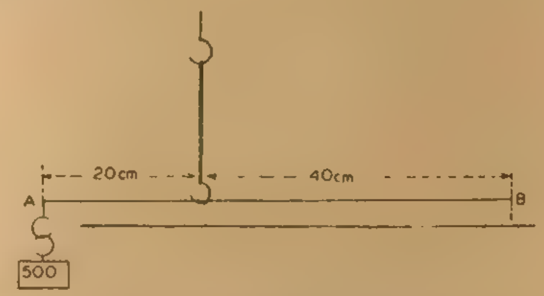


Fig. 3.8. A metre scale is suspended from a support and 500 g wt is kept at A

3. A metre scale is suspended as shown in Fig. 3.8. What is the weight at B required to keep it horizontal if a 500 g wt is kept at A in the diagram?
4. Why is it easier to unscrew a nut with a spanner?
5. Name some common examples of levers used in everyday life.

§ 23. Using the Lever does not Give any Gain

We have seen earlier that lever helps us to do some work. Suppose we take a weight of 1 kg and lift it through a height of 0.1 metre.

The work done $=1$ kg wt $\times 0.1$ metre $=0.1$ kg wt m. If the same

work is done by using a lever with a fulcrum in between the points at which the forces are applied and if this 1 kg wt is balanced by a 0.5 kg wt, we find that 0.5 kg wt drops through a distance of 0.2 metre (Fig. 3.9).

Fig. 3.9. Nothing is gained when a lever is used

In this case, the work done will be

$W = 0.5$ kg wt $\times 0.2$ metre
$= 0.1$ kg wt m.

The work done is the same as earlier.

We find that when a force is applied to the longer arm of the lever, we gain in force but lose in distance, *i.e.*, the distance through which the weight is lifted is less. For example, 0.5 kg wt falls through a distance of 0.2 metre while the weight of 1 kg wt is lifted through 0.1 metre only. Similarly, when a force is applied to the shorter arm of the lever we gain in distance but lose in force. But the total work done always remains the same. We can conclude from the above example that lever is used for convenience, but actually there is no gain in work by using a lever.

§ 24. Practical Applications

The principle of the lever is that a lever is balanced by two forces so that these forces are in inverse proportion to their arms. The most common example is the ordinary seesaw, where the planks on which the children sit is the lever with the fulcrum somewhere in the middle. The two children represent the force applied at the two ends.

If a child is seated at one end of the plank and a man at the other, it is obvious that the fulcrum will be placed nearer to the man so that the longer lever at the child's side will compensate for the greater weight of the man. A crow-bar used on railways is another example of this type of lever.

In practical application of a lever, it is necessary that we gain an advantage in force. A spanner used for opening a nut screw is a common example (Fig. 3.12). Here the force P is applied by the worker to the handle of the spanner. The two forces are (*i*) P, the force exerted by the hand and (*ii*) F, the force exerted by the nut on the spanner and these two forces are on the same side of the fulcrum but acting in opposite directions. Since the arm of the force P is greater than the arm of the force F, the worker in screwing

Fig. 3.10. A seesaw

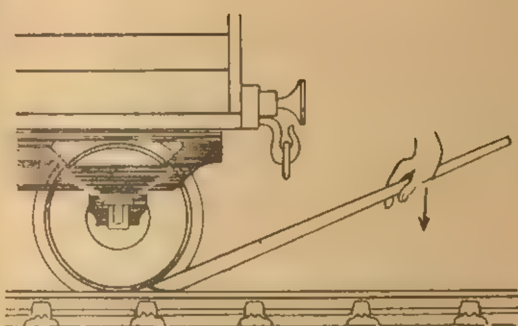


Fig. 3.11. A crow-bar used on railways

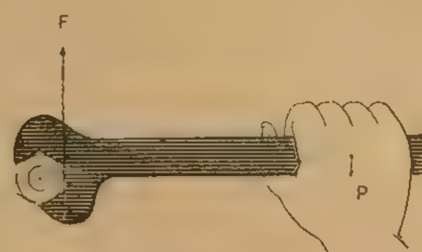


Fig. 3.12. A spanner used as a lever

the nut gains an advantage in force. Scissors are also a kind of lever. Here the fulcrum passes through the screw that connects the two blades of the scissors. The force *P* is the muscular force of the person. The two forces are (*i*) the force *P*, *i.e.*, muscular force of the person using the scissors and (*ii*) the force *F*, due to the resistance of the object being cut. Depending on the purpose for which scissors are generally used, the length of the two arms are chosen. For example, for ordinary scissors used for cutting paper or cloth, the length of the blades are long and there is not so much difference in the length of the handles and that of the blades.

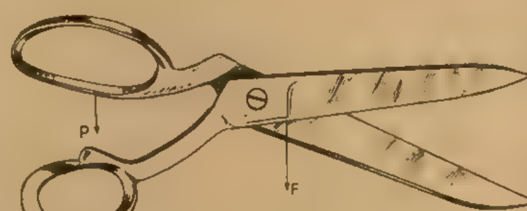
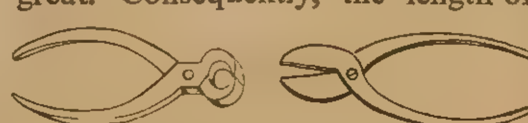


Fig. 3.13. A scissors: P—force exerted by fingers, F—force representing the resistance of the material being cut

The scissors are generally used for cutting metals such as tin, where the resistance of the metal is very great. Consequently, the length of



(*a*) (*b*)

Fig. 3.14. A nipper and a tinshear

the handles is much greater than that of the blades. The length of the handles is increased so that the force used for cutting is considerably increased to overcome this resistance. Fig. 3.14 shows a tin-shear, used for cutting metals, and a nipper. Different kinds of levers are used in different machines such as the handle of a sewing machine, the pedals or hand brake of a bicycle, the brake pedals in a car, or the key of a typewriter. They are shown in the following figures (Fig. 3.15 to 3.18).

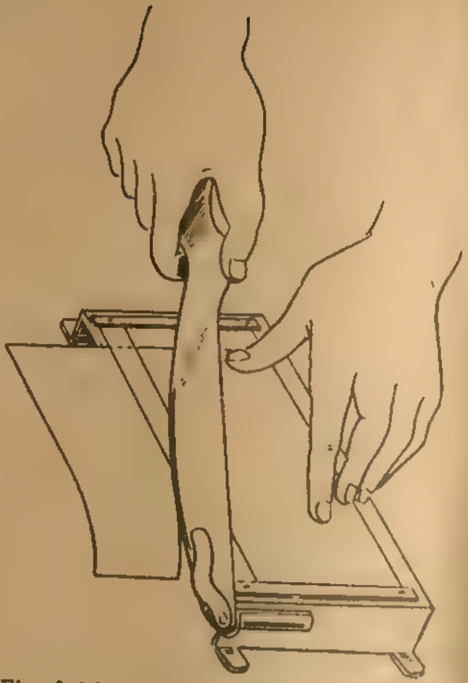


Fig. 3.16. A photographic paper cutter

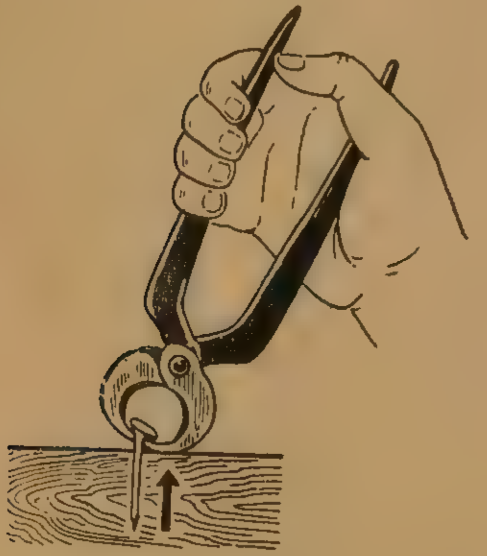


Fig 3.15. Pincers used for pulling out nails

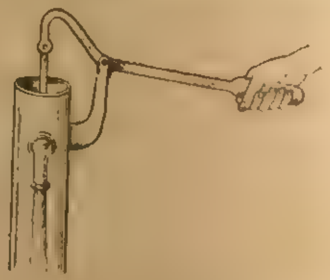


Fig. 3.17. The handle of the water pump

Fig. 3.18. The arm acts as a lever when an object is lifted

Exercise

1. Find the fulcrum and the lever-arm of levers shown in Fig. 3.15 to 3.18.
2. Why is it easier to cut a strip of metal with a tinshear, when the screw is nearer to the blades?
3. In Fig. 3.19 a boy is using a stick for carrying a load in two different ways. In what position of the load, the boy will feel less pressure on his shoulder?

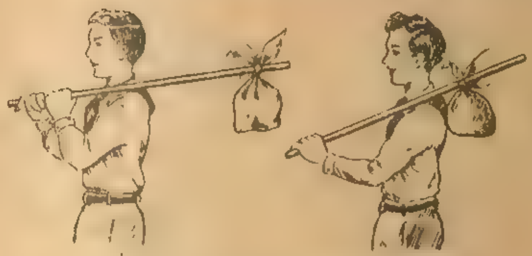


Fig. 3.19. A boy is using a stick to carry a load

Fig. 3.20. A lever in equilibrium under the action of weight

4. Fig. 3.20 shows a lever in equilibrium under the action of some weights. Will it still remain in equilibrium if two equal weights are attached to it as shown in Fig. 3.21? What will happen if two additional weights are attached to it at the two ends? (see Fig. 3.22).

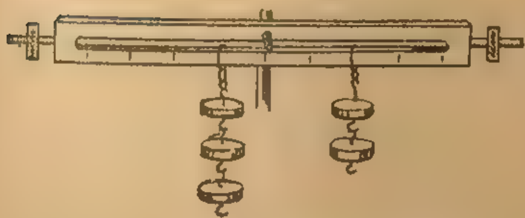


Fig. 3.21. Figure illustrating question No. 4

Fig. 3.22. Figure illustrating question No. 4

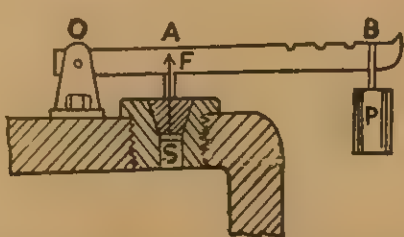


Fig. 3.23. Safety valve of a steam boiler. O is the fulcrum, OB and OA lever-arms of forces: P—the counter weight, F—force due to steam pressure on S

5. The cross section of a safety valve is shown in Fig. 3.23. Study the position of the fulcrum and the lever-arms. What are the forces acting on this lever?

§ 25. Pulley

When a bucket of water is raised from a well, a rope is used for the purpose. It becomes much more convenient if, instead of using rope alone, a small wheel with a groove in it is used and the rope passes over the wheel. This arrangement is called a pulley. It consists of a small circular disc. A groove is cut in its circumference. The disc can revolve freely about the axis passing through its centre at right angles to the plane of the disc. Fig. 3.24 illustrates how a pulley can be used for lifting loads. When the axis of the pulley is supported in a framework, called the block, and the block remains fixed, the pulley is called a fixed pulley. It helps a person to pull the weight in a more convenient direction. You can see from Fig. 3.25 how the rope is attached to the load that has to be lifted and the other end is pulled by the man. The axis of the pulley is not moving at all and therefore this is a fixed pulley.

The fixed pulley can be regarded as a lever where the lever-arms are

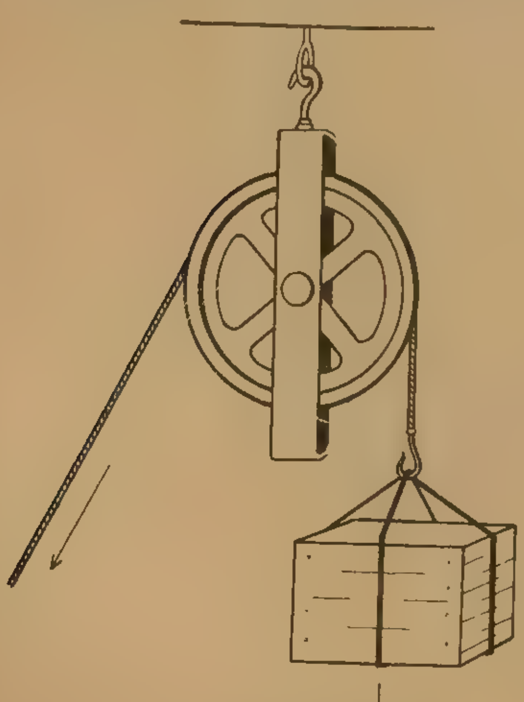


Fig. 3.24. A fixed pulley

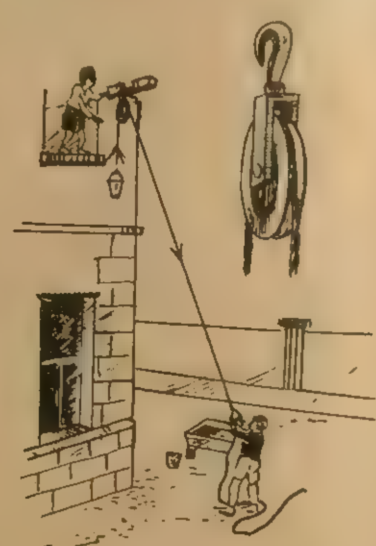


Fig. 3.25. A fixed pulley is used for lifting loads in buildings

equal to the radius of the wheel. Fig. 3.26 shows the direction of the

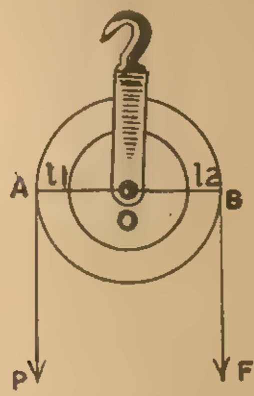


Fig. 3.26. Equilibrium of forces on a fixed pulley

two forces and the lever-arms with respect to the fixed point O. Here $OA=l_1$ and $OB=l_2$ are the two lever-arms. Force F represents the force exerted by the man and force P is the weight of the load to be lifted. From the figure, you can see that the force P tends to rotate the pulley in the counter-clockwise direction while the force F tends to rotate it clockwise. From the principle of moments given earlier, a lever will be in equilibrium when the moments of the two forces are equal, *i.e.*, $Pl_1=Fl_2$. Since l_1 is equal to l_2, the two forces P and F are equal. In other words,

$$\boxed{\mathbf{F=P}}$$

In our discussion of the fixed pulley, we have always neglected the friction between the rope and the pulley. Neglecting friction, we can say that the force exerted is equal to the weight of the load. It does not give any advantage in force. When the load, which is lifted, moves uniformly through a certain distance, the rope is also pulled down through the same distance. Here the main action of the pulley is to change the direction of the force. So by using a fixed pulley, we cannot gain either in force or in distance.

Hence, it is seen that the fixed pulley is used only to change the direction of the force.

§ 26. Movable Pulley

A similar arrangement in which the pulley itself moves up when the load is lifted is called a movable pulley. Fig. 3.27 shows a movable pulley which is not fixed to a support. Here the string or rope which passes around it is tied to a support at one end and the weight to be lifted hangs from a little frame attached to the pulley as shown in the figure. The other end of the rope moves parallel to the first one and the pulley moves up along with the rope, when the rope is pulled from above.

If an arrangement is made so

that instead of pulling a rope in the upward direction, a spring balance

Fig. 3.27. Movable pulley

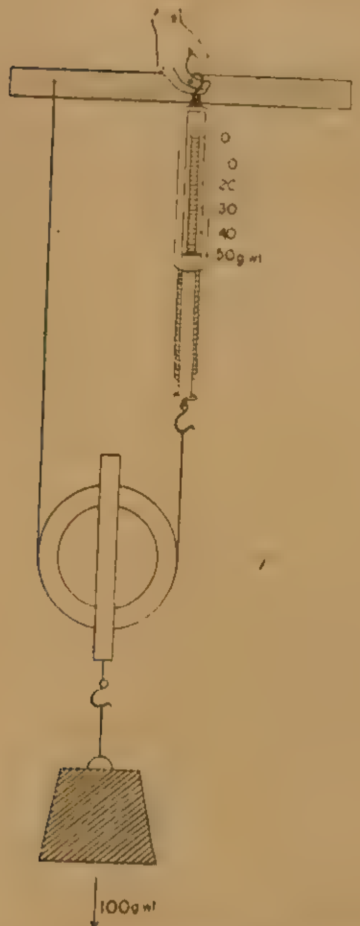


Fig. 3.28. In a movable pulley the weight lifted is double the effort

is attached to the free end of the rope as shown in Fig. 3.28 and the weight is lifted, then the force exerted as indicated by the spring balance is equal to half the total weight of the load lifted and the pulley (generally the weight of the pulley is negligibly small compared to the weight of the load, and it can be neglected). The forces exerted in a movable pulley are shown in a schematic diagram in Fig. 3.29. It

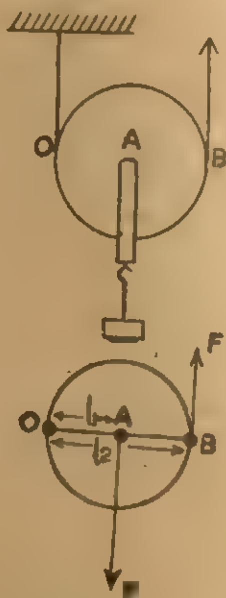


Fig. 3.29. A schematic diagram of a movable pulley

can be considered as a lever with one arm twice as long as the other with the fulcrum at one end at the point O and the arms of the lever equal to OA and OB. From the principle of moments in lever as stated earlier:

$$\boxed{Pl_1 = Fl_2}$$

Here,

$$OA = l_1$$
$$OB = l_2$$
$$\because \quad OB = 2OA$$
$$\therefore \quad l_2 = 2l_1$$

So if we put the value of l_2 in equation (i), we get,

$$Pl_1 = F \times 2l_1$$

$$\boxed{\therefore \; F = \frac{P}{2}}$$

Thus we find that the force necessary to lift the load by using a movable pulley is half the weight of the load. If you carefully study the facts given above, you will realize that it is definitely more advantageous to use a movable pulley than a fixed one (Fig. 3.30).

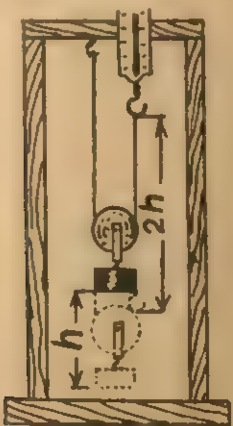


Fig. 3.30. A movable pulley does not save work

If an experiment is conducted where the weight is lifted through a height h, the position of the load, and the spring balance are as shown in the figure. The distance through which the spring balance is lifted is $2h$. It shows clearly that though the force required is half of the total weight, the distance moved by the spring balance is double. So it is seen that, to raise a load of weight P to a height h, we are required to do work W_1 given by the relation,

$$W_1 = P \times h$$

If the same load is raised to the same height by using a movable pulley, the work W_2 done is given as,

$$W_2 = \frac{P}{2} \times 2h = P \times h$$
$$\therefore W_2 = W_1$$

Hence, by using a movable pulley, it is found that though the gain in force is doubled, the loss in distance is also two times more. Therefore, we cannot have any gain in work. Sometimes the combination of a fixed and movable pulley

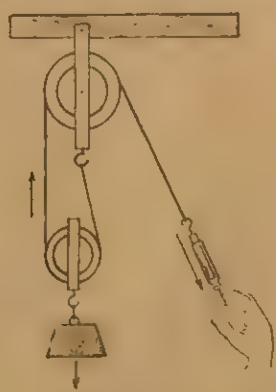


Fig. 3. 31. Combination of a fixed and a movable pulley

is used for lifting the load as shown in Fig. 3.31. Here the fixed pulley is attached to the beam and the movable pulley moves up when the man triesto pull the rope in the downward direction. Movable pulleys are used where a big load is to be lifted by applying a small force.

§ 27. Laboratory Work

Equilibrium of Forces in a Lever and a Pulley

1. Equilibrium of forces in a lever

Apparatus: lever, a spring balance, weights, ruler, a holder.

Procedure :

1. Set up an arrangement as shown in Fig. 3.5.
2. Note down the clockwise and counter-clockwise movements of the lever under the action of each of the applied forces separately.
3. Attach a weight to the left arm of the lever and find out the distance of the point to which a second weight twice the size of the first should be attached to keep the lever in equilibrium.
4. Measure the distance from the fulcrum to the points of application of the forces. Enter the observations in the following table:

No.	*Force rotating the lever anti-clockwise, F*		*Moment of force (g wt × cm)*	*Force rotating the lever clockwise P*		*Moment of force (g wt × cm)*	*Ratio of forces P/F*	*Ratio of arms l_1/l_2*
	Force in g wt	*Lever-arm in cm*		*Force in g wt*	*Lever-arm in cm*			
1.								
2.								
3.								

5. Repeat the experiment for different distances of the lever-arm and different weights so that the lever is in equilibrium.

2. Equilibrium of forces in a movable pulley

Apparatus: Two pulleys, thread, a stand, weights, a spring balance and a scale.

Procedure :

1. Set up a combination of a fixed and movable pulley. The threads from the movable pulley running up must be parallel.

2. Find a weight that will balance the movable pulley.
3. Consider the movable pulley as a lever.
4. Measure the diameter of the movable pulley.
5. Attach a weight to the hook of the movable pulley.
6. Balance the weight on the movable pulley with the spring balance by attaching it to the end of the thread passing over the fixed pulley.
7. Write down the reading of the spring balance and the weight attached to the movable pulley. Find out the force balancing the weight on the pulley, if force is equal to the reading of the spring balance minus the weight balancing the pulley without any load.
8. Repeat the experiments three times with different weights.
9. Enter your observations in the following table:

No.	*Weight in g wt*	*Arm in cm*	*Moment (g wt × cm)*	*Force balancing the weight in g wt*	*Arm in cm*	*Moment (g wt × cm)*
1.						
2.						
3.						

Verify the results of the experiments with the principle of moments.

Exercise

1. A weight was lifted 7 metres with a movable pulley. If the force exerted by the man at the end of the rope is 16 kg wt, calculate the work done by him.
2. Explain how the fixed pulley should be used to gain an advantage in distance.
3. A movable pulley is used for lifting a load through a height of 1.5 metres. What will be the distance through which the rope has to be pulled up in this process?
4. Can a boy whose weight is 45 kg lift a weight of 54 kg with the help of a fixed pulley when he is standing on the floor?
5. Fig. 3.32 shows a long pole used to press hay down on a cart. What is the type of pulley used for this purpose?
6. A weight of 5 kg is attached to the short end of a lever. Pressing on the long end, a boy lowers it 10 cm doing work equal to 0.25 kg wt m.

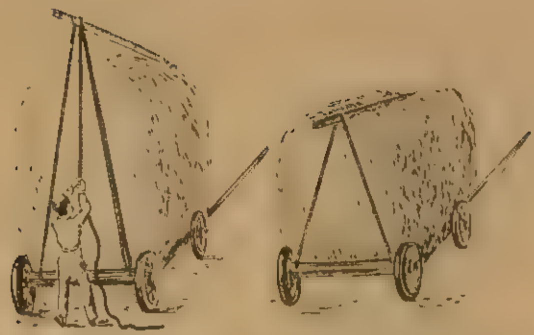


Fig. 3.32. A long pole is used to press hay down on a cart

Find : (a) the force with which the boy presses the lever;
(b) the height through which the weight is lifted.

§ 28. Windlass

Windlass is a simple machine used to draw up water from wells. It consists of a drum to which a handle has been attached, both being mounted on a straight wooden stand. Here, a long rope is wound round a cylinder and the free end of the rope is attached to a bucket which goes in and out of the well. The clockwise motion of the handle winds the rope round the drum, thus raising the bucket, while the anti-clockwise motion of the handle lowers the bucket. The forces acting at different points are diagramatically shown in Fig. 3.34. O is the centre round which the windlass rotates, the distance OC is the radius of the circumference, which the handle describes. P represents the force due to the weight of the bucket and water, F represents the force exerted by the person while drawing water.

If a straight line is drawn through the points C, O and B, and the

Fig. 3.33. Windlass

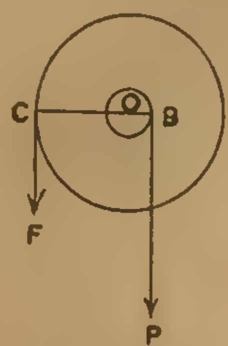


Fig. 3.34. A schematic diagram of windlass

system is compared with that of a lever, then r and R represent the radii of the cylinder and the circle described by the handle respectively.

From the principle of lever

$$F \times R = P \times r$$

or $$\frac{F}{P} = \frac{r}{R}$$

$$\boxed{\therefore\ F = P\,\frac{r}{R}}$$

Since $\frac{r}{R}$ is less than unity, hence F is less than P. The ratio of the force on the handle to the weight lifted is the same as the ratio of the radius of the cylinder to that of the circle described by the handle. **So, when we use windlass, we gain in force but lose in distance.**

Windlass forms a part of many complicated machines. Here also we do not gain any advantage in work as in the earlier examples of a lever.

Exercise

1. The diameter of the cylinder of a windlass is 20 cm, and the radius of the circumference described by the handle is 60 cm. If the weight of the bucket containing water is 12 kg wt, how much force is required for pulling the bucket of water up?
2. A windlass is used for lifting a load of 150 kg wt with a force of 10 kg wt. Draw a schematic diagram of the windlass and calculate the radius of the circle the handle describes, when the radius of the cylinder is 10 cm.
3. Explain the working of a wheel and axle.

§ 29. Efficiency of a Machine

We have discussed some simple devices which are used as aids for doing certain types of work. We have seen that so far as work is concerned we do not gain anything. They only help us to gain either in force or in distance which is necessary for a particular type of work.

We have also mentioned earlier that we neglect the frictional force developed between the rope and the pulley and in other machines. The useful work obtained is always somewhat less than the work done in setting the machine into motion. If the total work done on the machine is represented by W_t and the useful work derived from the machine is W_u, then the efficiency E of the machine is expressed by the

relation,

$$E = \frac{W_u}{W_t}$$

The efficiency of a machine is always less than one because the useful work derived from a machine is always less than the total work done on the machine, as some part of the work is wasted in overcoming the resistance between different parts of the machine. Efficiency is generally expressed in terms of percentage and is always less than 100 per cent.

$$E = \frac{W_u}{W_t} \times 100\%$$

§ 30. Inclined Plane

All of you are familiar with a plane surface. When a plane surface is horizontal and another plane surface makes an angle with the first one, it is called an inclined plane. Perhaps you have seen that a heavy load is lifted upwards with the help of a wooden plank used in an inclined way. Fig. 3.35 shows

Fig. 3.35. Wooden planks are used for moving heavy boxes on a slope

how big boxes or barrels can be lifted easily on to the cart by using some wooden planks. Fig. 3.36 shows a boy using a plank for walking up the wall. You must have also seen that the roads on a mountain have an upward slope. If a section of such a road is taken as shown in Fig. 3.37, it will give

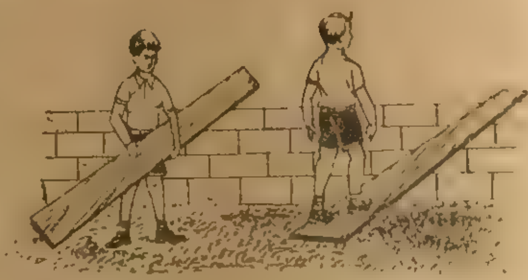


Fig. 3.36. Climbing the wall with the help of wooden plank

Fig. 3.37. Sectional diagram of a road on a mountain

you a view of an inclined plane. Fig. 3.38 shows a gangway and a ramp as examples of an inclined plane. The sectional diagram of

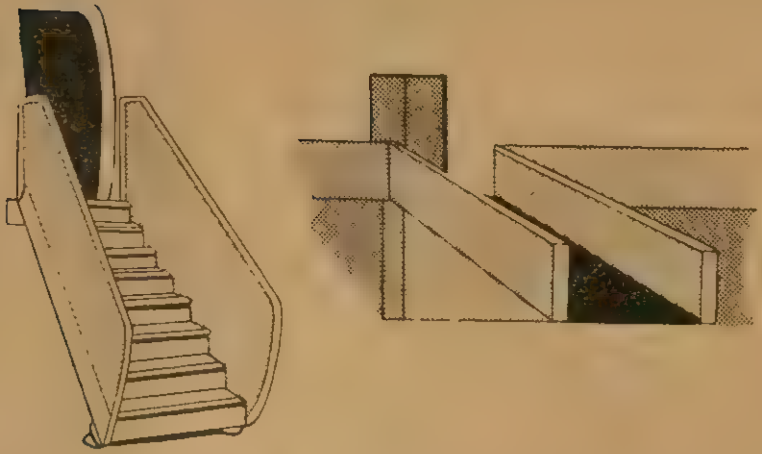


Fig. 3.38. A gangway and a ramp

one such inclined plane and the forces acting upon the body as it is lifted in the upward direction are shown in Fig. 3.39.

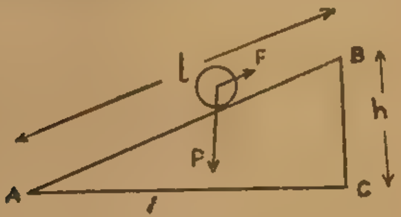


Fig. 3.39. Sectional diagram of an inclined plane

If h is the height through which a body moves and p represents the force due to the weight of the body, then W, *i.e.*, the work done, is equal to $W=P\times h$. If the body is moved along an inclined plane the length of which is given by l, the work done will be equal to $W_2=f\times l$ where f is the force moving the body up the inclined plane. You know that in any machine, there is no gain in work. So here in the case of inclined plane, we must have,

$$W_2=W_1 \text{ or}$$
$$f\times l=p\times h$$

$$\boxed{\therefore\ f=p\frac{h}{l}}$$

We can see from the above expression that if the length of the inclined plane is many times greater than its height, then a small force is required to move the body in the upward direction.

§ 31. Laboratory Work to Calculate the Efficiency of an Inclined Plane

Apparatus : Inclined plane, a wooden block with a hook, a dynamometer, weights, etc.

Procedure :

1. Measure the length and height of the inclined plane. Attach the

dynamometer to the block and then pull the block uniformly.

2. Using blocks of different weights, repeat this experiment several times without changing the height of the inclined plane.

3. Enter your observations in the following table.

4. Calculate the efficiency of the inclined plane and express it in terms of percentage.

No.	*Traction force in kg wt*	*Length of inclined plane in m*	*Work of traction force in kg wt 'm'*	*Weight of block with load in kg wt*	*Height of inclined plane in m*	*Useful work in kg wt m*	*Efficiency (in %)*	*Average Efficiency*

Exercise

1. A barrel weighing 200 kg wt has to be pushed up an inclined plane 10 metres long and 2.5 metres high. Is it possible to do it by using a force of 30 kg wt?
2. Suppose a mountain road rises by 4 metres in 20 metres. A small cart weighing 50 kg wt is to be pulled up the road. Calculate the force required to do so if we neglect friction.

§ 32. Transmission Belts and Gears

We have discussed earlier that in rotatory motion the different points of a body move along circumferences, the centres of which are on a stationary straight line called the axis of rotation. Some bodies rotate faster than others. You must have noticed that in a watch the second-hand describes the full circle in one minute, the minute-hand describes the full circle in one hour and the hour-hand describes the full circle in 12 hours. The angular speed of a body is measured by the angle through which a body rotates in unit time. For example, when a wheel makes 60 rotations in one minute it will make one rotation in one second. In one complete rotation the body rotates through an angle of 360°. The angle through which a body rotates in one second determines the speed of rotation and this is expressed in terms of rotations per minute. The following table will give you an idea of the speed of rotation in some machines used in engineering.

Wheels of a windmill	...	60 rotations per minute
Wheels of water turbine	...	100 -do-
Wheels of a cycle	...	100 -do-
Wheels of a motor car	...	500 -do-
Aircraft propeller	...	1,200 -do-
Engine crank-shaft of a motor car	...	4,200 -do-
Weaving loom shuttle upto	...	18,000 -do-

You have learnt in the first chapter on motion that in the linear motion of a body the speed is given by the distance travelled in unit time : $V=s/t$. When a body is rotating, different parts of the body taken separately will have some linear speed. This speed will depened on the radius of the circle along which the point moves. For the same number of rotations the linear speed will be greater if the radius of the circle described is greater. For one complete rotation the length of the circumference of a circle of radius $r=2\pi r$. If the body makes n rotations in one minute, the length described in one minute will be equal to $2\pi rn$. We have seen that the speed $V=s/t$. If t is the time taken by the body to make n rotations, then the linear speed of a point on the body will be $V=\frac{2\pi rn}{t}$, where r is the radius of the circle.

If $t=1$ minute$=60$ seconds, $V=\frac{2\pi rn}{60}$

A rotatory motion is generally transferred from one part of the machine to another part by some simple mechanism. In a bicycle a person uses muscular force to rotate pedals and the rotatory motion is transferred by means of a chain to the wheels of the bicycle. In a sewing machine belts are used for transferring this sort of rotatory motion from one wheel to another. These are known as transmission belts. Perhaps you remember that in earlier discussions on friction we mentioned that in these types of machines, precaution is taken so that the leather belt does not slip. For this usually grease is used on the belt and it is tightened so that the rotatory motion is transmitted from the driving wheel A to the driven wheel B (Fig. 3.40). When the belt is directly connected between the two wheels, the rotatory directions of the driven wheel and the driving wheel are the same but when the belt is crossed, the directions of rotation of the two wheels are opposite to each other.

Gear transmission

A large number of machines

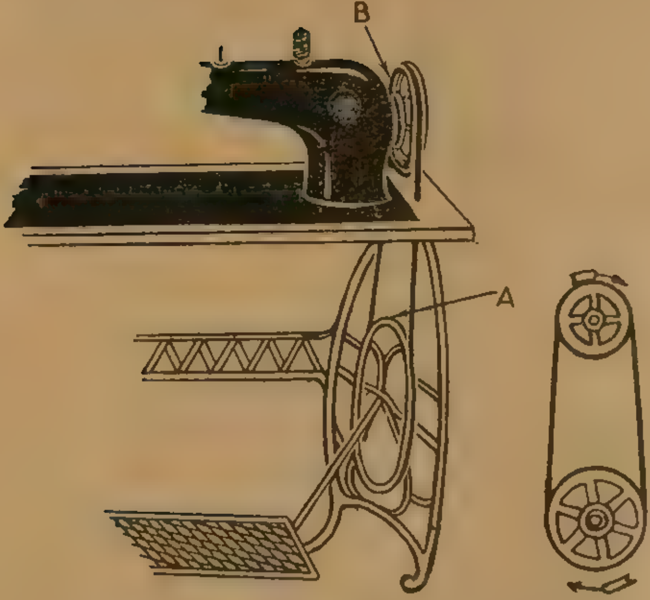


Fig. 3.40. Transmission belts in a sewing machine

nowadays make use of gears or toothed wheels for transmitting power from one shaft to another shaft. The usual method of such transmission is that the teeth of one wheel are meshed directly into the teeth of the other wheel as shown in Fig. 3.41. You will be able to see

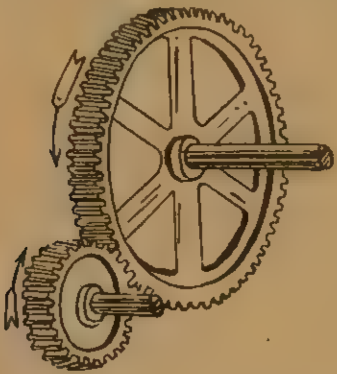


Fig. 3.41. Gear wheels

in the following figures (Fig. 3.42 and Fig. 3.43) how gear transmission is used in some machines such as sewing machines and motor cars.

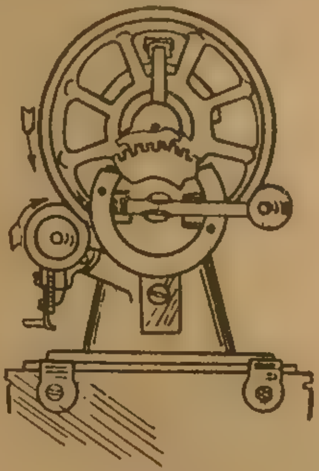


Fig. 3.42. Gear and friction transmission in a sewing machine

Friction transmission

Sometimes friction is used for the purpose of transmitting rotatory motion from one part of a machine to the other. The most common

Fig. 3.43. Automobile transmission gears

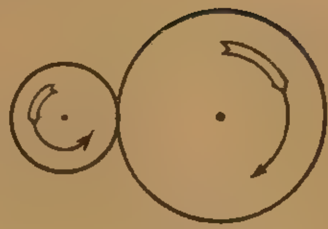


Fig. 3.44. Sectional diagram of friction transmission in a sewing machine

example is in the sewing machine where the spool used for thread is fitted in the particular manner as shown in Fig. 3.44. Here the friction is between the main driving wheel and the rubber belt in the small wheel. When one wheel rotates, this friction causes the small wheel to rotate and in this process the thread is wound on the spool.

Exercise

1. An ordinary bicycle is moving with a speed of 15 km per hour and the radius of the wheel is about 70 km. Can you give an approximate idea of how many revolutions the wheel will make in 1 second ?
2. Name some of the modes of transmissions used in the machines mentioned earlier.
3. Explain how friction transmission is used in a sewing machine.

§ 33. Energy

In the beginning of this chapter we have discussed the meaning of the term work in science. Work is done when a body moves to a certain extent under the action of some external force.

When a body is capable of doing some work, it is said to possess energy.

Energy may be classified in different categories like mechanical energy, electrical energy, light energy and so on. You will learn about the last two in detail later on. Here we shall discuss only the mechanical energy. There are two types of mechanical energy:

(i) Kinetic energy
and (ii) Potential energy.

§ 34. Kinetic and Potential Energy

Kinetic energy: All bodies in motion possess some kinetic energy. To understand it more clearly take the help of the following experiment.

Fig. 3.45 shows a metallic cylinder rolling down an inclined platform and hitting the wooden block B, which is at rest on the horizontal plane. The moving cylinder A, when it hits the block B, moves it to a distance. Thus the moving cylinder A does same work. It does work because of its motion. This ability of the moving cylinder A to do same work is due to motion is known as its **kinetic energy.**

Thus a flying aeroplane, a moving car or a bicycle, each possesses the same value of kinetic energy.

Now let us find out the factors which determine the value of the kinetic energy. For this purpose, use the same arrangement as given in Fig. 3.45.

First you will see how the speed of the moving cylinder A, reaching the horizontal plane, depends upon the height of the point on the inclined plane from which it starts moving.

If the same cylinder starts moving from different heights of the same inclined plane, you will observe that the moving cylinder covers greater distance along the horizontal plane when the height is greater. When the same cylinder covers greater distance along the horizontal plane, it must have greater speed in that case.

So it is seen from the experiment that the body left moving from a greater height acquires greater speed at the horizontal plane.

Now it can be shown that the value of kinetic energy of a body depends upon the speed of the body.

Let the same cylinder start moving from different heights of the inclined plane and strike against the wooden block at the horizontal plane. You will see that when the

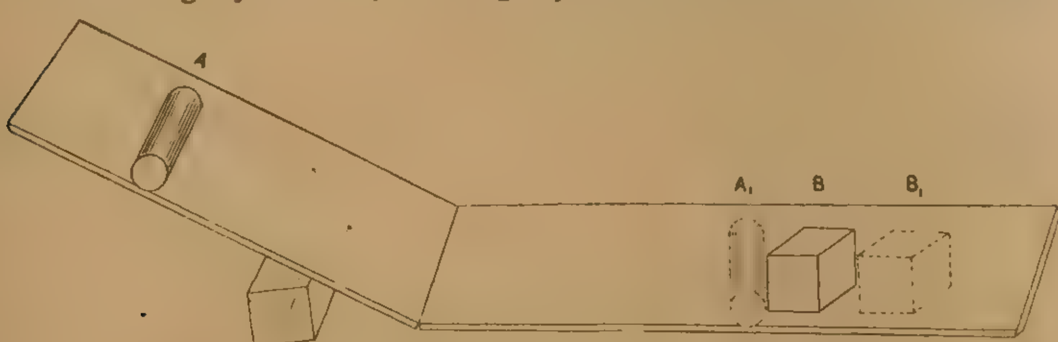


Fig. 3.45. A metallic cylinder rolling down an inclined plane

cylinder starts moving from greater height it displaces the wooden block to a greater distance. Now you know that when the same block is displaced to a greater distance, the more mechanical work is performed, so we conclude that the kinetic energy of a body depends upon the speed of the body; more the speed, more is the kinetic energy.

Now by another experiment with the same arrangement we can see that the kinetic energy of a moving body depends upon the mass of the moving body.

Let the two cylinders of different masses start moving from the same height of the inclined plane and strike against the block on the horizontal plane in two different experiments. You will observe that the block is displaced to a greater distance by the heavier cylinder. So we conclude that the kinetic energy of the body also depends upon its mass; the heavier the body the greater is its kinetic energy.

So, it is seen that the value of kinetic energy depends upon both (1) the speed of the body and (2) the mass of the body.

Exercise

1. In which of the two rivers, one flowing down a mountain and the other in a plane, a cubic meter of water has the greater kinetic energy ?
2. Which of the two, a loaded truck and a car, both moving with equal speed, has greater kinetic energy?
3. Under what conditions two moving bodies with different speeds can have equal kinetic energy ?
4. Two moving bodies of different masses have equal kinetic energy. Under what conditions it can be possible ?

Potential energy: You know that every body has its weight. This weight of the body is the force of pull of the earth upon the body. Now if you raise any body from the ground, you are overcoming this force of earth as well as displacing the body against this force. Thus in doing so, you are doing some mechanical work. This mechanical work done by you is not wasted, but is stored in the body raised from the ground. This stored energy can be obtained back by dropping such a body.

Experiment

If a body is dropped on a sandy ground, it covers a distance under the sand. It does so against the resistance of the sand and so it does some mechanical work. Thus we see that any body raised to a height with respect to any thing, it develops an ability to do work. This ability of a body of doing work because of being raised to a height with respect to same body is known as its **potential energy.**

Now let us find out the factors which determine the value of the potential energy of a raised body. For this, let us make the arrangement as shown in Fig. 3.46. Here the same body is let

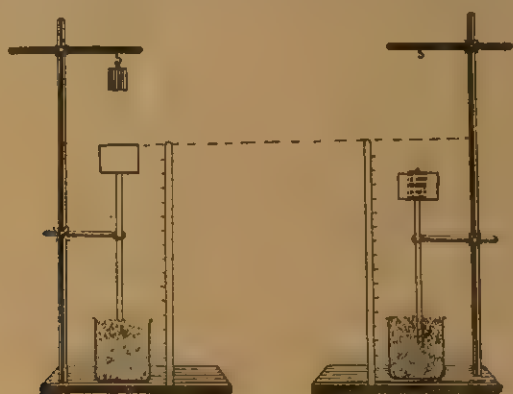


Fig. 3.46. Determining the value of potential energy

to fall from different heights. We observe that greater the height from which the body falls, the greater is the distance through the sand covered by the rod. Thus we see that the same body falling from a greater height does more mechanical work than when it falls from a lesser height. In other words, the potential energy of a body increases with the height of the point to which the body has been raised.

Let us repeat the same experiment with two bodies of different weights. If they are let to fall one after another from the same height, it can be seen that in the case of heavier body, the rod covers a greater distance through the sand. So the potential energy of a body also depends upon its weight. Heavier is the body, greater will be its potential energy.

Thus we conclude that the value

of the potential energy by virtue of its position depends upon (1) the weight of the body and the (2) height at the point to which the body has been raised with respect to the body under reference.

There is also another type of potential energy. Take the case of a compressed spring. It has some ability to do work. This can be seen as follows:

If we take a spring and keep a body in contact with it, the body remains at its position. Here the spring in its non-compressed form does not do any work. Now if we keep the same body in contact with the same spring in its compressed form, the body will be displaced as soon as the spring is released (Fig. 3.47). Here the spring does some mechanical work. It has done work because of its compressed form. Such an ability to work due to the special form of the body is also known as its potential energy.

In a watch the spring is wound first and the work done in process of winding remains stored in the spring as its potential energy. The compressed spring when released can set the other wheels in motion. When a compressed gas is taken inside a cylinder fitted with a piston and is allowed to expand, it pushes the piston in the outward direction

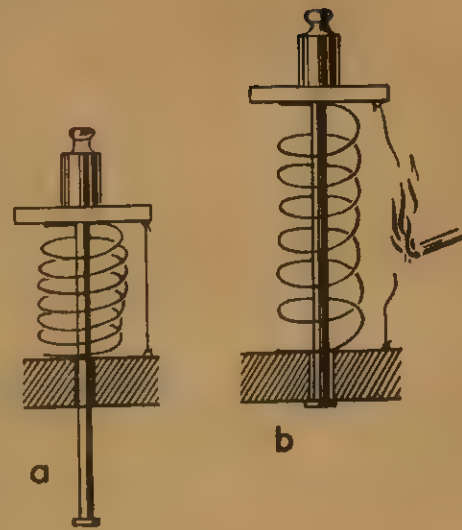


Fig. 3.47. Compressed spring does work when it uncoils

with a force. It shows clearly that the compressed gas possesses potential energy which is moving the piston.

A great amount of potential energy is obtained by putting a dam across a river. By putting the dam across the river, the level of water in the river is raised, thereby the potential energy of the water is increased. The water of such a river falling from a height behind the dam can rotate the wheel of a turbine, generating electricity.

So, from the above examples, we conclude that the potential energy of a body is due to its position or its form.

Exercise

1. Two cylinders, one of brass and another of wood, having equal volumes are raised to the same height. Which of the two has greater potential energy ?
2. Consider one cubic meter of water both at the source and at the mouth of the river. Which of the two has greater potential energy ?
3. What types of mechanical energy are possessed by a flying aeroplane ?
4. Under what conditions two bodies of different weights raised to different heights can possess equal potential energy ?

§ 35. Transformation of Energy

You know that there are two types of mechanical energy. These are (i) kinetic energy and (ii) potential energy. In the case of a body the sum of its kinetic energy and potential energy is its total mechanical energy. When you raise a body to a certain height and if it is at rest there, it has only potential energy. Here the total mechanical energy of the body is equal to its potential energy.

If the body is moving on a horizontal plane, it has only kinetic energy and no potential energy with respect to the plane. Here the total mechanical energy of the body is equal to its kinetic energy.

In some cases, the body possesses both types of energy as in the case of a flying aeroplane. As the aeroplane is flying at the same height it has some potential energy. Again, as it is moving with the same speed, it has also kinetic energy. Similarly, in the case of a missile, it also possesses both kinetic as well as potential energy.

Examples given below will give you some idea of how one form of energy changes into another form.

Fig. 3.48 will help you to under-

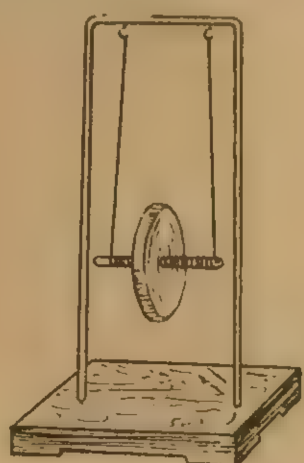


Fig. 3.48. Apparatus showing the transformation of potential energy into kinetic energy

stand the transformation of energy. It shows a disc. When the disc is lifted to a height the thread is wound around its axis. When the disc is raised, it possesses a certain amount of potential energy.

If the disc is now released, it starts rotating as it moves downwards, thus losing its potential energy. While falling it acquires kinetic energy. When it reaches the rest point, the disc possesses sufficient amount of kinetic energy to raise almost to its previous height. In practice, part of the energy is used to overcome friction, so the disc will not reach its initial height. When the disc reaches the top it falls again and it moves up and down in this way.

In this experiment when the disc falls, its potential energy is transformed into kinetic energy and when it moves up its kinetic energy is again tranformed into potential energy.

When a stone falls from a height its potential energy decreases but its kinetic energy increases. In nature this change of energy from one form to the other is known as **transformation of energy.**

Energy of the wind is utilized in windmills, where the moving masses of air press against the inclined planes of the wings and set them into motion. Windmills are used to draw water from wells, to pump water into water-towers and also for other purposes.

When two elastic bodies strike each other, for example, a rubber ball bounces on the floor or a steel marble is allowed to fall on a steel slab, the tranformation of energy that takes place there is more complicated in nature. When a steel marble is raised above a steel slab, the higher we lift it the greater is its potential energy. Now the marble is allowed to fall. When it falls, its potential energy decreases but its kinetic energy increases. When the marble strikes the base, both the marble and the base are compressed and the kinetic energy of the marble is transformed into the potential energy of the base and the marble. Because of the elasticity of the base and the marble, they will regain their initial shape. The marble will bounce on the base and the potential energy will again be transformed into kinetic energy of the marble.

Any phenomenon in nature is always accompained by the transformation of one form of energy into another.

Dams are built across rivers, so that the level of water is appreciably high, thus increasing the potential energy of the water. When the water falls from a height, its potential energy is changed into kinetic energy, and when it passes through the wheels of the turbines in the power

station (Fig. 3.49), it imparts its kinetic energy to the turbine wheels. The wheels which are connected to an electric generator produce electricity.

This example shows how the mechanical energy is transformed into electrical energy. Fig. 3.49 will give you some idea of how a turbine is used.

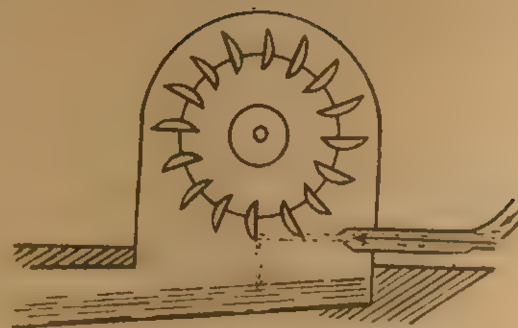


Fig. 3.49. A water-turbine

Exercise

1. Give examples of bodies possessing potential energy and kinetic energy.
2. State the transformation of the energy in the following cases : (*a*) falling of water in a waterfall, (*b*) when a spring is wound and then released.

Summary and Conclusion

1. Mechanical work is done when the following two conditions are fulfilled:

   (i) A force acts upon a body and
   (ii) Under the action of this force, the body moves.

2. The amount of mechanical work, W, is calculated with the help of the following formula :

   $W = F \times S$

   where $F =$ the force

   and $S =$ the distance through which the body moves.

3. Mechanical work is measured in the units of either kg wtm or joule.

   1 Kgwtm = 1 Kgwt × 1 m

   1 J = 1N × 1 m.

4. Power is the amount of work done in one second, i.e.,

$$P = \frac{W}{t} \text{ Where } W = \text{the work done in time 't'}$$

and also, $P = F \times V$ Where F is the pulling force and V is the speed of uniform motion.

$P_{av} = F \times V_{av}$ Where V_{av} is the speed of non-uniform motion.

5. Power is measured in the following units:

(i) $\frac{\text{Kgwtm}}{\text{Sec}}$ (ii) Watt (iii) HP

$$1 \frac{\text{Kgwtm}}{\text{Sec}} = \frac{1 \text{ Kgwtm}}{1 \text{ sec}}$$

$$1 \text{ Watt} = \frac{1 \text{ joule}}{1 \text{ second}}$$

$$1 \text{ HP} = 76 \frac{\text{Kgwtm}}{\text{Sec}}$$

6. The arm of the lever is the shortest distance between the fulcrum and the line of action of the force.
7. Moment of a force is equal to the product of the arm of the lever and the magnitude of the force, i.e.,

$M = F \times l$......Where M = the moment;
F = the force and l = the arm of the lever.

8. A lever remains in equilibrium if the colckwise and anti-clockwise moments about the fulcrum are equal.

$$P \times l_1 = F \times l_2$$

9. In practice, a lever is used only to have a gain in force.

Since $F = P \frac{l_1}{l_2}$

So, when $l_2 < l_1$,

we have, $F < P$.

10. A fixed pulley remains in equilibrium if the pulling force is equal to the load to be lifted,

i.e., $F = P$ where P is the wt of the load to be lifted.

By using such types of pulley, we neither gain in force nor in distance.

So they are used to change the direction of the force only which is more convenient in some cases.

11. A moveable pulley remains in equilibrium if the pulling force is equel to half of the weight to be lifted.

i.e., $F=\frac{1}{2}P$ Where P is the weight of the load to be lifted.

By using such types of pulley, we gain in force by two times but at the same time lose in distance by two times.

12. Windlass remains in equilibrium under the condition,

$$F \times R = P \times r$$

Where, r -radius of the cylinder and R the radius of the circle described by the handle.

In practice, the windlass is used for a gain in force.

Since $F=P\frac{r}{R}$ and $\frac{r}{R}<1$

So, $F<P$.

13. A body on an inclined plane remains in equilibrium under the condition,

$$F \times l = p \times h$$

Where l and h are the length and height of the inclined plane, respectively.

An inclined plane is used for a gain in force.

Since $F=P\frac{h}{l}$ and $h<l$

So, $F<P$

14. By using any simple machine or modern complex machine we cannot gain in work. What we gain in force, we lose in distance simultaneously and *vice versa* in any machine.

15. All types of machines have some sort of friction. So, the useful work done by the machine is always less than the total work done.

16. Each machine has an important characteristic known as its efficiency. It is measured as the ratio of the useful work and the total work done.

i.e., $E=\frac{Wu}{Wt}\times 100\%$

17. In all machines, the motion from one part to the other part

of the machine is transferred by using any of the following types of transmission.

(i) Gear transmission, (ii) Belt transmission and (iii) Friction transmission.

18. All bodies capable of doing work possess some energy.
19. There are two types of mechanical energy:
    (i) Kinetic energy and (ii) Potential energy.
20. All bodies in motion possess some kinetic energy.
21. The amount of kinetic energy of a body depends upon:
    (i) the speed and (ii) the mass of the body.

    Greater the speed or mass of the body, the greater is the amount of its kinetic energy and *vice versa.*
22. Potential energy of a body is either the energy of interaction between two bodies at a distance (a body lifted to a height with respect to another body) or the energy of interaction between different parts of the same body (energy of pressed or expanded spring).
23. The amount of potential energy of interaction between two bodies depends upon (i) the height to which the body has been lifted with respect to another body and (ii) the weight of the body.

    Greater the height or weight of the lifted body, more is the amount of its potential energy.
24. The sum of the kinetic and potential energies of a body is equal to its total mechanical energy.
25. All phenomena in nature are accompanied by the transformation of one form of energy into another form of energy.

CHAPTER IV

Thermal Phenomena

§ 36. Thermal Phenomena

In your daily life you must have noticed various physical changes associated with the heating and cooling of bodies. On heating, ice melts and changes from the solid state to the liquid state. Similarly, to join two wires or two different metals we have to heat them first. Water taken in a vessel starts boiling if kept on a fire for sometime. Similarly, when the iron rim is to be put on the wheels of a bullock cart, it is first expanded by heating. After it has been put on the wheels, it is contracted by pouring cold water over it to make it tight over the wheel. You can also observe another case of expansion while preparing *chapatis* in your house. When the half-baked *chapati* is put on the fire directly, it becomes inflated due to the expansion of water vapour in it. These and the various other processes which show the effect of heating and the changes produced in a body by heating it are called **thermal phenomena.**

By a systematic study of these and other thermal phenomena, man has succeeded in making the steam engines and the petrol engines. These steam and petrol engines are used for driving trains, ships, aeroplanes and motor cars. Fast moving jet planes and rockets used for launching artificial satellites also depend upon the practical application of such thermal phenomena.

§ 37. Expansion of Bodies

Solids, when heated, always expand, but this expansion is so small that it is not possible to see it without using some special device.

Experiment

Take a thin steel wire which is clamped at one end as shown in Fig. 4.1, while the other end rests on a needle to which a

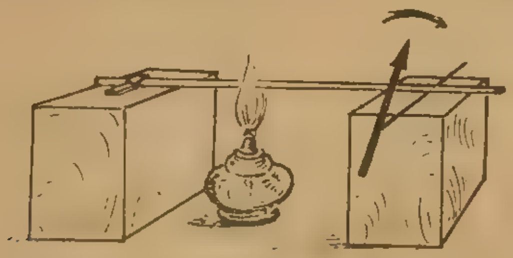


Fig. 4.1. The expansion of a solid : The needle under the wire rotates

pointer is attached. When the wire is heated, its free end expands and the pointer moves in one direction. If the wire is cooled, it moves in the opposite direction.

If the same experiment is repeated by taking an aluminium wire or a copper wire, a similar effect is observed. Thus, you will find that the wires expand on heating.

The expansion of solids can be observed by another experiment. A copper or brass ball is taken which can pass freely through a ring when suspended from a stand by a metallic chain as shown in Fig. 4.2. If the ball is heated sufficiently it does not pass through the ring but when it is allowed to cool down for sometime, it again passes through it. We can conclude from the above experiments that solids expand on heating and contract on cooling.

It has also been found by experiments that the amount of the thermal expansion for different materials are different even if their temperatures are increased equally.

Fig. 4.2. When cold, the ball passes through the ring, but when heated, it expands and gets stuck in the ring

For example, two rods of equal length, one of copper and the other of iron expand by different amount even if their temperatures are increased by the same amount.

§ 38. Expansion of Liquids

Experiment

The following experiment shows that liquids also expand on heating.

A glass flask filled with water or some other liquid up to the brim, is taken. A narrow glass tube is passed through the cork as shown in Fig. 4.3. The liquid in the flask will partly fill the

Fig. 4.3. On heating, the flask expands first and the level of liquid falls. When the liquid is heated, it expands and the level rises

tube. The level of the liquid is marked by fixing up a rubber ring. If the flask is heated the level of the liquid comes down first; the wall of the flask expands due to heating and its volume increases. As heating is continued, the level of the liquid reaches the mark after sometime and continues to rise. The final level of the liquid is much more than what it was earlier. The expansion of the liquid as shown in this experiment is quite appreciable and can be observed without using any special device.

From the above experiment, it can be easily seen that on heating, the expansion of a liquid is much more than that of a solid.

§ 39. Expansion of Gases

The expansion of gases may be demonstrated by a simple experiment. A thin-walled glass flask fitted with a cork is taken. A narrow glass tube bent at right angles is inserted through the cork.

A small drop of coloured liquid is introduced into the tube. If the flask is made warmer by just holding it with hands, the coloured index moves forward (Fig. 4.4). If the hand is removed and the air in the flask is allowed to cool down, the index moves in the opposite direction. The same phenomenon can be observed by using any other gas. This experiment clearly shows that gas expands much more than liquids and solids.

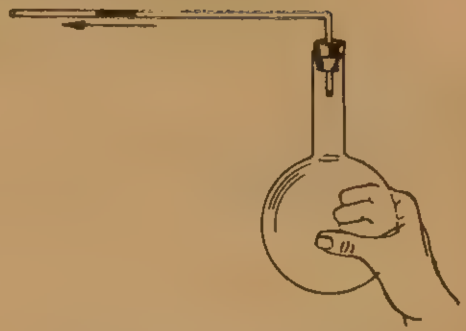


Fig. 4.4. A glass flask with the index showing the expansion of a gas

From the above experiment we conclude that solids, liquids and gases expand on heating and contract on cooling.

Exercise

1. Take a small wooden board in which there is a hole so that one coin can just pass through it. If we heat the coin, do you think it will be able to pass through the hole?
2. Take a wooden board and a needle big enough to stick to one side of the board while the other end of the needle rests freely on the board as shown in Fig. 4.5. Another needle is fixed to

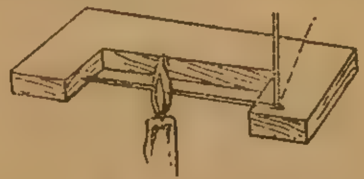


Fig. 4.5. Figure illustrating question No. 2

the eye of the first needle and a third needle used as a pointer is kept near the second one. Heat the first big needle by means of a spirit-lamp. You will notice that the second needle stuck through the eye of the first one will be deflected from its original position. Explain what this experiment demonstrates.
3. A glass stopper, when it gets stuck to the neck of the bottle, is heated first in order to open it (Fig. 4.6). Can you give the reason ?

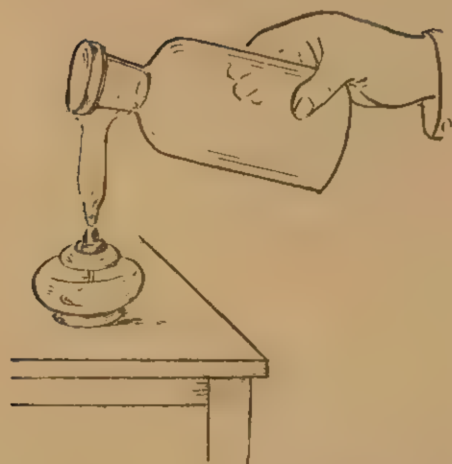


Fig. 4.6. Figure illustrating question No. 3

4. A metallic tyre is heated first before fixing it into the rim of a wheel in a cart. Explain why.
5. Give a few examples of the expansion of solids from the facts you have observed in everyday life.
6. You want to store kerosene oil for summer. If you buy a tin in winter, do you think it will be right on your part to make it filled up to the brim ?
7. Take an empty glass tumbler and keep it inverted on a vessel containing some water. If you hold the glass with your hand for some time, you will see bubbles of air coming out through the water. Explain what is happening in this experiment.
8. A piece of paper is burnt inside a glass tumbler and the tumbler is then inverted quickly over a trough of water. Explain why the level of water in the tumbler rises (Fig. 4.7).

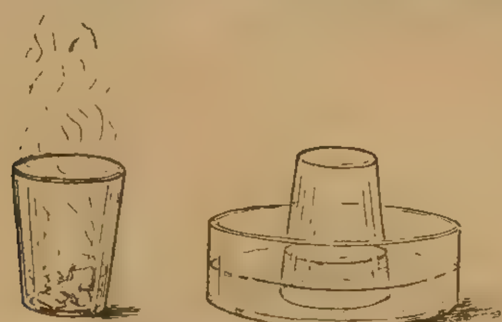


Fig. 4.7. Figure illustrating question No. 8

§ 40. Temperature

Take cold water in a vessel and start heating it for making tea. In the beginnig, you can easily dip your finger in the water. But as the water gets more and more heated, you cannot keep your finger in the water. This sensation of feeling cold, warm and hot by touching with the finger gives us an idea of relative hotness and coldness of water. This quality by which we can compare between the relative hotness and coldness of bodies is known as **temperature.**

We feel warmer in summer than in winter because of the difference in the temperature of the air surrounding us.

If you want to measure the temperature of a body, you cannot merely depend upon the sensation produced when you touch it. For example, let us take three vessels filled with cold, warm and hot water respectively and dip our right hand in the hot water and the left hand in the vessel containing cold water. If we now put both hands simultaneously in the warm water, the left hand will feel the water as warm; the right hand will feel the same water to be cold.

It is thus evident from the above experiment that by merely touching a body we cannot get the temperature accurately. The device for measuring the temperature of a body accurately is called a **thermometer.**

§ 41. Thermometer

Now you know that substances expand when heated and contract when cooled. This principle is utilized for the construction of a thermometer. It consists of a thin-walled glass tube of uniform and capillary bore. There is a glass bulb at one end of the tube. The glass bulb and part of the stem is filled with mercury by alternately heating and cooling it. The bulb is then heated so that the mercury fills up the entire tube and the air inside the bulb is completely driven off. The tube is now sealed. When the bulb is allowed to cool down there is contraction in its volume as well as that of mercury contained in it. Consequently, the level of mercury falls in the tube, since on cooling, liquids contract much more than solids. The themometer thus constructed is then kept suspended in a glass flask containing boiling water as shown in Fig. 4.8. Care should be taken so that the bulb of the thermometer does not touch the water but records the temperature

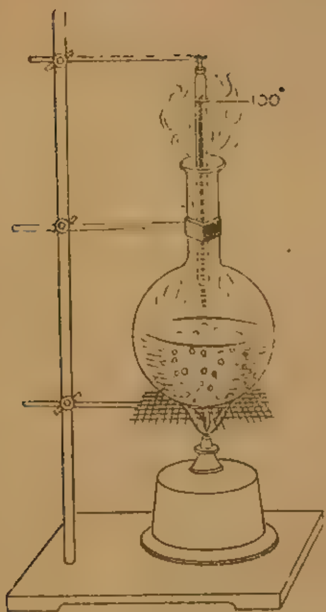


Fig. 4.8. Upper fixed (100°C) point of a thermometer

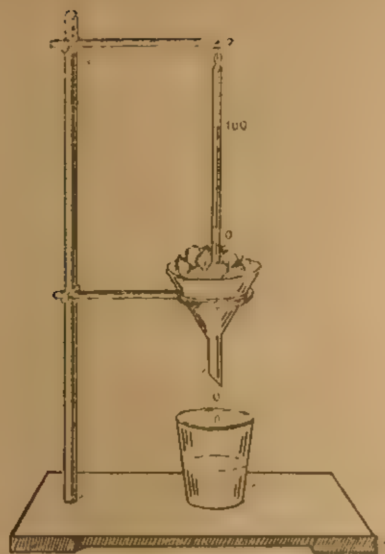


Fig. 4.9. Lower fixed (0°C) point of a thermometer

of steam. When the position of mercury in the thermometer remains stationary for some time, it is marked off by a line on the glass tube. The number 100 is written against it giving the temperature of steam. The thermometer is then kept in melting ice as shown in Fig. 4.9.

When the level of mercury in the tube falls to a particular level and remains constant for some time, the position is marked off again by writing the number zero against it. These two lines indicating the temperature of melting ice (zero) and that of steam (100) are known as the **fixed points** of the thermometer. The distance between the fixed points is then divided into 100 equal parts and each part of it is called a **degree.** The scale of the thermometer thus taken is known as Celsius scale and it is denoted by writing the letter C to the numbers. For instance, 100°C is temperature of boiling water and 0°C is the temperature of melting ice respectively. A thermometer is shown in Fig. 4.10(a).

Temperatures below zero are indicated by adding a minus sign to the numbers. Thus —15°C means that the temperature is 15 degrees below zero. Mercury is generally taken as a thermometric substance because its expansion is more uniform than that of other liquids. But it solidifies at —39°C. Hence it is not possible to use a mercury thermometer for measuring very low temperatures. In such cases, in place of mercury, alcohol is used

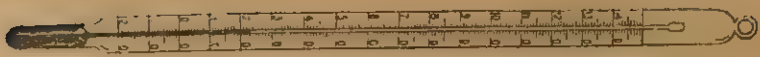


Fig. 4.10 (a). Thermometer

because it solidifies at a much lower temperature, i.e., —114°C. There is one disadvantage in using alcohol for measuring high temperatures. It starts boiling at 80°C while the boiling point of mercury is 357°C. Therefore, a mercury thermometer is used for measuring high temperatures.

When a thermometer is kept in a place, the mercury inside the bulb acquires the temperature of the surrounding medium and the temperature is measured by the thermometer.

§ 42. Use of a Thermometer

When a thermometer is used for measuring the temperature of a liquid, it should be kept inside the liquid for some time before the reading is taken. For measuring the room temperature it should be kept near the window. While for measuring outside temperatures, it should be kept in the shade, rather than keeping it directly exposed to the rays of the sun.

Exercise

1. There are two thermometeres containing the same amount of mercury inside the bulb but the diameters of the capillary tubes are different. When they are used for measuring the temperature of steam, do you think that the heights of the mercury levels will be same in both ?
2. Take a glass tube with a bulb at one end and immerse the open end in a coloured liquid taken in a vessel as shown in Fig. 4.10(b). Explain why some coloured liquid will rise in the tube when the bulb is heated first and then cooled. If this arrangement is used as a thermometer, do you think any change in the atmospheric pressure will affect the reading of such a thermometer ?
3. In summer, the water of a river appears to be warmer in the evening than in the afternoon. But if the temperature of the

Fig. 4.10 (b). Thermometer (earlier type)

water is actually measured, it is found to be 30°C in the afternoon and about 10°C in the evening. The temperature is higher in the afternoon than in the evening. Explain why.

§ 43. Practical Applications of Thermal Expansion in Engineering

You have already seen that solids expand on heating. But all solids do not expand equally. Some solids expand more than others. This can be shown by the following experiment.

Experiment

Take two rods, one made of copper and another made of iron. Join them together as shown in Fig. 4.11. When they are heated, the strip gets curved with the copper strip on the convex side and the iron on the concave side. But when they are cooled in ice, the curvature is in the opposite direction. It is thus evident that when iron and copper are heated through the

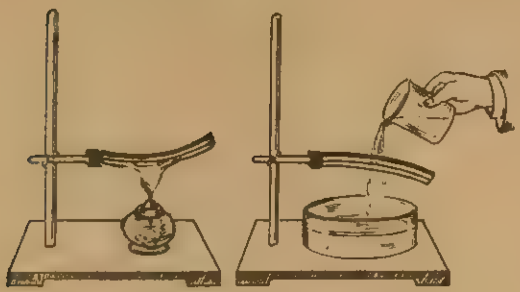


Fig. 4.11. Bimetallic strips

same range of temperature, copper expands more than iron. Similarly, on being cooled, the contraction of copper is more and the metal strips will bend in the opposite direction.

The expansion of different metals can be compared if we take rods made of different metals of one metre length and determine the increase in length for 1°C rise in temperature. The following table gives the expansion of different solids of one metre length when heated through 1°C.

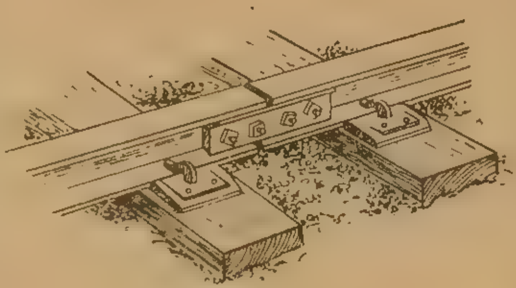


Fig. 4.12. Small gaps for expansion in railway tracks

	in mm
Glass	0.010
Iron	0.012
Copper	0.017
Brass	0.018
Aluminium	0.024

If you study the above table carefully, you find that the expansion is negligibly small. Even this small expansion of solids on heating has wide application in engineering.

When rails are laid on railway tracks, a small gap is left in between the joints as shown in Fig. 4.12. This is done with the object of leaving space for expansion due to variation in temperature. Special types of metallic strips are used in factories between steam pipes so that the pipeline does not burst due to expansion. When the pipeline expands these strips are bent as shown in Fig. 4.13. These are known as **compensators.** When large bridges are built, one end of the bridge is kept fixed on the ground, while the other one rests

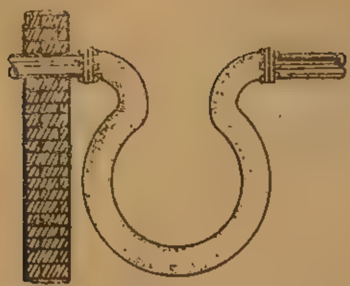


Fig. 4.13. Compensator in a steam pipe

on rollers to allow room for expansion as shown in Fig. 4.14.

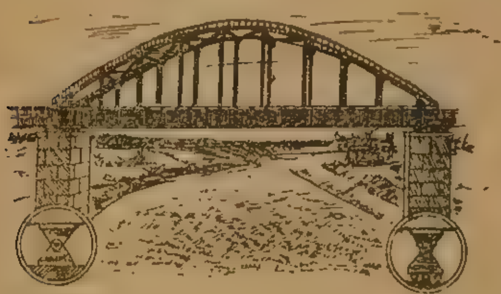


Fig. 4.14. One end of the bridge is fixed while the other rests on rollers to allow expansion

The illustrations given above are practical applications of thermal expansion in engineering.

While discussing the expansion of substances, we have seen that the expansion of liquid is much more than that of solids. If we take one litre of water and heat it through 1°C, its volume increases by 0.00032 litre. If the liquid is heated in air-tight vessel, increase in pressure becomes so great that it may even break a vessel into pieces unless proper precaution is taken. This effect is utilized in pressure cookers where food can be prepared more quickly than when it is cooked in the ordinary way.

In this chapter we have discussed about the expansion of gases and we have seen that gases expand much more than liquids. If we take any gas and heat it through 1°C, its volume increases by 1/273 of its volume at 0°C. If an experiment of this type is conducted in a closed vessel so that the volume cannot increase, pressure inside increases by 1/273 of its pressure at 0°C.

§ 44. Transfer of Heat

Perhaps you have observed that when a stove is lighted in the kitchen, the air inside the room becomes a little warmer. If this air is allowed to come out through an open window, it gradually cools down. If a metal spoon is dipped in a cup of hot tea, the spoon becomes a little warmer and the temperature of the tea falls slightly.

These examples indicate that bodies at higher temperature lose heat, and consequently, their temperature falls. When bodies gain heat, their temperature rises.

It shows that there is a mutual exchange of heat between bodies at different temperatures.

Heat is transmitted not only from a body at a higher temperature

to another body at a lower temperature but also the exchange may take place between different parts of the same body if they are at different temperatures. For example, if we heat a steel rod at one end for a long time while holding it at the other end, the rod becomes so hot that it may burn our fingers. This phenomenon, where heat actually passes from one body to another or from one part of a body to another part is called **transfer of heat**. Flow of heat takes place only in a particular direction, *i.e.*, from bodies at higher temperature to bodies at lower temperature, as water flows from a higher to a lower level.

Heat continues to flow as long as there is difference in temperature between the different parts of a body. The flow of heat ceases when *their temperature* becomes equal. This condition is expressed by what is known as **temperature equilibrium.**

There are three distinct processes by which the transfer of heat may take place: conduction, convection and radiation.

§ 45. Conduction

In an example already given, you have seen that the spoon becomes hot when it is dipped in a cup containing hot tea. In this case the end of the spoon which remains inside the liquid becomes hot first and then heat is transferred to the colder end held by the hand.

The process by means of which heat is transferred in a solid body from one part to the other is known as **conduction.**

Let us try to understand the process of heat conduction by some practical illustrations.

Experiment

Take a wooden stick and put it into the fire. It will burn, but you will not feel the heat at the other end where you are holding it. Can you explain it? It means that wood is a bad conductor of heat. Similarly, if in place of wood you take a glass rod and heat its one end, you will find that it is possible to hold the glass rod even when the heated end becomes red hot. It shows that heat does not flow so easily in glass; in other words, we can say that glass is also a bad conductor of heat, like wood.

If the experiment is repeated with an iron rod in place of wood or glass, it is found that after sometime the metal rod becomes very hot, and it is no longer possible to hold it. We can conclude from the above experiment that iron is a good conductor of heat.

The conduction of heat can be understood very clearly from the following experiment:

Take a copper rod and fix it to a stand. Fix some small iron nails on the copper rod with the help of molten paraffin wax as shown in Fig. 4.15. When the copper rod is heated with a spirit-lamp at one end, the iron nails drop one by one, starting from the end where the rod is heated first. It shows that heat passes slowly from one end to the other end of the rod.

Fig. 4.15. Observation of the conductivity of copper

All metals are good conductors of heat. We can compare the conduction of heat in different metals by taking two rods, one made of copper and another made of steel, and repeating the above experiment. The arrangement is shown in Fig. 4.16, with iron nails fixed on both the rods. The common terminal is heated by a spirit-lamp. When heating is continued the wax melts and the nails start falling. The iron nails start falling from the copper rod much sooner than from the other rod. The above experiment shows that copper is a better conductor of heat than steel.

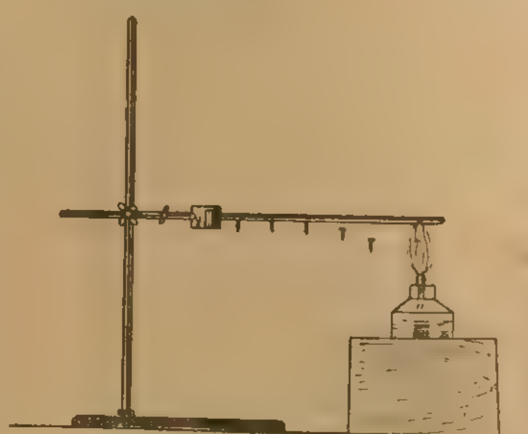


Fig. 4.16. Comparison of the conductivities of copper and steel

Now let us consider the conduction of heat in liquids.

A test-tube filled with water is taken. A piece of ice is placed at the bottom of the tube with the help of a sinker and the test-tube is held in an inclined position as shown in Fig. 4.17. When the water

Fig. 4.17. Water is a poor conductor of heat

in the upper part of the test-tube is heated, it is observed that even if the water starts boiling in the upper part of the test-tube, the piece of ice *does not* melt completely but remains at the bottom of the test-tube. This proves that water is a bad conductor of heat.

Similarly, we can show that air is also a bad conductor of heat. A test-tube is held in an inclined position and the thumb is inserted

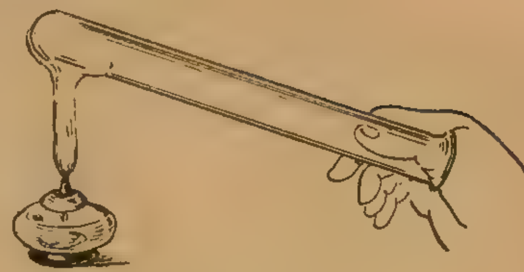


Fig. 4.18. Air is a poor conductor of heat

air inside the test-tube is heated over a spirit-lamp, we do not feel any heat. This shows clearly that air is also a bad conductor of heat.

Silver and copper are good conductors but wood and leather are bad conductors. Wool, hair, feathers, paper, cardboard, asbestos and cork are very bad conductors of heat. In porous bodies there is a lot of air in the gap which prevents the free flow of heat between different parts of the bodies. Also, the transmission of heat by conduction cannot take place in vacuum.

Usually, liquids and gases are poor conductors of heat. However, mercury and other metals in the melted state are good conductors of

Correction Slip

Page	For	Read
96	*Fig. 4.15. Observation of the conductivity of copper*	*Fig. 4.16. Comparison of the conductivities of copper and steel*
	Fig. 4.16. Comparison of the conductivities of copper and steel	*Fig. 4.15. Observation of the conductivity of copper*

piece of ice is kept wrapped up in such a coat, do you think the ice will melt ?

4. In severe winter would you prefer to use an old quilt or a new one ?
5. Which one do you think will be warmer in winter, a hut with a thatched roof or a building with a concrete roof?
6. When hot liquid is poured into a thick glass tumbler, it breaks; but it can be boiled in a glass vessel, even when it is made of thick glass. Explain.

§ 46. Convection

When we place our hands over a hot stove we feel that warm air is slowly rising in the upward direction. When a paper spiral is placed over an electric bulb, it starts moving in the upward direction as shown in Fig. 4.19. If a wet handkerchief is dried up by keeping it above a lighted stove, it moves slightly, showing an upward movement of the stream of air just above the stove. The above observations can be explained in the following way.

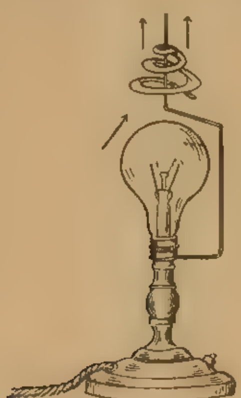


Fig. 4.19. Convection current over a glowing electric lamp

The air in contact with the stove or the electric bulb becomes warm and expands. When it expands, it becomes lighter and moves in the upward direction, while the cold air from the surroundings takes its place. The same phenomenon can be observed when a liquid is heated in a vessel. The liquid at the bottom, which is in direct contact with the vessel, becomes warm and its density decreases. Layers of liquid at the bottom thus become lighter and move in the upward direction. The layers of cold water near the surface move in the downward direction and then the whole liquid is gradually heated. An experiment to show the movement of water when it is heated at the bottom can be performed by taking some water in a flask. Adding a few crystals of potassium permanganate, the actual movement of the streams of coloured

water, as it moves up, can be clearly seen (Fig. 4.20).

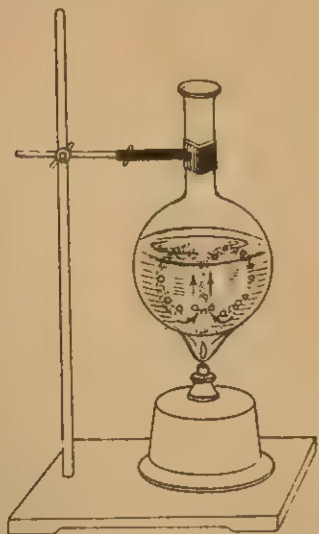


Fig. 4.20. Convection in liquids

This process by which heat is transmitted in liquids and gases by actual movement of material particles is known as **convection.**

Air inside the room, as it becomes warmer, rises up, while the cold air from outside takes its place, thus setting up convection currents inside the room.

Due to non-uniform heating of the earth's surface, a convection current is set up in the the earth's atmosphere and produces wind. We know that layers of air just above the earth's surface near the equator are hotter than those at the poles. The heated air becomes lighter and rises and its place is taken by the air from the colder regions. Thus on the surface of the earth, air blows from the colder regions towards the equator and in the upper atmosphere a stream of air current flows from equator towards the poles.

On summer days, land is heated more by the sun's rays than water in the sea. The air heated by the ground becomes lighter and moves up while the cooler air coming from the sea takes its place. Thus the direction of the breeze during the day is from the sea towards the land. At night the land surface cools down sooner and the direction of the breeze will be just the opposite, *i.e.*, from the land towards the sea.

§ 47. Practical Applications of Convection in Engineering

(*i*) *Draught*

You have already learnt that the air surrounding a stove becomes lighter due to expansion and starts moving in the upward direction. Cold air from the surrounding place fills up the space thus creating a circulation. In a furnace, the weight of the hot gas inside the chimney is less than the weight of cold air outside. Therefore the cold air from outside displaces the air inside the chimney. When the cold air from outside rushes into the

furnace it creates a natural draught. This depends upon the temperature of the gas inside the chimney as well as its length. In factories and power stations, usually, high chimneys are used to increase the draught. How a draught is created in a chimney can be understood from the Fig. 4.21.

Fig. 4.21. A draught is created in a chimney

(*ii*) *Central water heating system*

Many houses are heated by the central water heating arrangement. Here, (Fig. 4.22), a boiler is used for heating the water and it is installed in the basement. There is a main pipe connecting the boiler to the expansion tank. From the main pipeline runs a network of pipes connected to the radiators, of which, at least one is placed in each room. The radiators are usually placed under a window, which is the coldest part of the room. The system works on the principle of convection current. Each radiator is connected to the boiler by two pipes, one for carrying the hot water to the radiator and the other

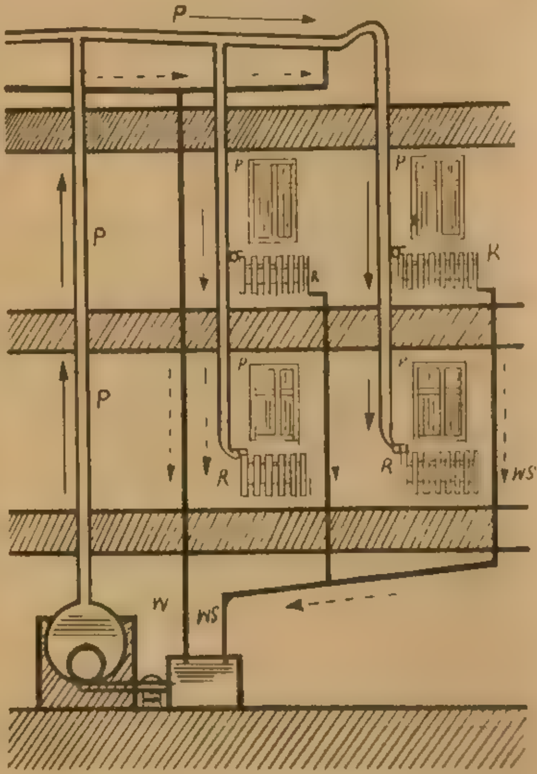


Fig. 4.22. Central water heating

for sending the cold water back to the boiler. Because warm water is lighter than cold water, the pipes carrying the cold water are at the bottom. The function of the expansion tank can be understood in the following way. The heating system, *i.e.*, the boiler, pipes and radiators must be kept filled with water. Thus, it is necessary to allow room for expansion when the water is heated. It also helps in maintaining a regular flow of water in the radiator because when the water is cooled and contracts, the expansion tank

provides the additional supply of water for the radiators and the pipes.

(iii) *The cooling system in an automobile*

Radiators are used in petrol engines in motor cars for cooling the engine. In this arrangement, the radiator consists of a system of thin pipes with a connecting rubber tube. When water gets heated by the walls of the cylinder of the engine it becomes lighter and moves upwards as shown in Fig. 4.23, and the cold water in the radiator takes its place. Water in the radiator is cooled down by the flow of air from the ventilator.

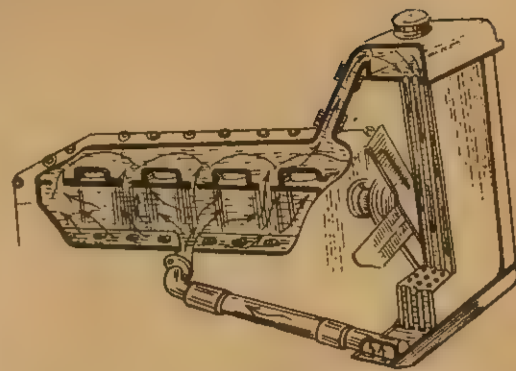


Fig. 4.23. Cooling system in an automobile

§ 48. Radiation

You have already learnt two processes of transmission of heat. There is another process by which heat may be transmitted from one place to another. It can be understood from the following experiment.

Experiment

Take a small glass flask. A glass tube bent at right angles passes through the cork fitted to the flask. The small flask is covered with dark soot on one side. A small quantity of coloured liquid is introduced into the tube that is bent at right angles. It acts as an index when it moves along a scale attached to the glass tube. The arrangement shown in the Fig. 4.24 is called a **thermoscope.**

Take a piece of red-hot rim iron ball (say 5 kg wt) and keep it at a distance of 50 cm from the thermoscope. We find that the index moves forward as the air inside the flask is heated and expands. We know that air is a bad conductor of heat. Therefore, the air between the flask and the iron ball could not have conducted the heat so quickly. You also know that the sun is at a

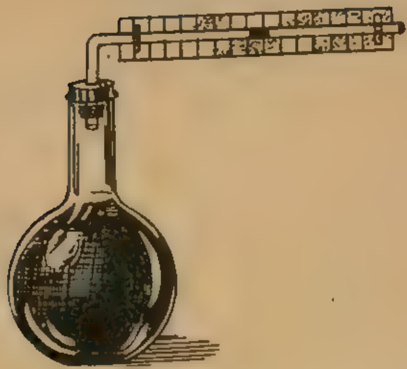


Fig. 4.24. Thermoscope

great distance from the earth and there is no air in the interven-ing space. Even then, we get heat from the sun.

In the experiment above, the thermoscope gets heat from the red-hot iron ball by the same process by which the earth gets its heat from the sun. If a screen of cardboard is placed between the hot body and the thermoscope, the rays coming from the hot body are cut off and the index does not move at all. This could not have happened if the thermoscope were heated due to the circulation of hot air in between these bodies. The process by which heat can pass from one place to another without the intervention of any material medium is known as **radiation**.

In the same experiment, if you expose the side of the flask coated with soot to the iron ball, you will find that the index moves much faster than it does when the un-coated side of the flask is exposed to the hot body. It shows that a black surface can absorb heat more quickly than a white one.

By a similar experiment it can be shown that dark bodies *lose* heat more rapidly than bodies with white surfaces. Water can be hot for a longer time if it is kept in a *shining* kettle.

§ 49. Practical Applications of the Transfer of Heat

(*i*) *Davy's safety lamp*

Perhaps you have noticed that if a copper wire gauze is held over the flame of a burner, the gas does not burn above the gauze. The copper wire gauze, which becomes red-hot, being a good conductor, spreads the heat more

quickly, and the gas above it does not ignite. On the other hand if the wire gauze is held in a position shown in Fig. 4.25(a), and the gas

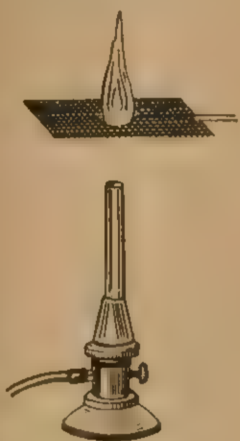


Fig. 4.25 (a). The copper wire gauze being a good conductor of heat, spreads the heat and the gas does not burn below the gauze

Fig. 4.25 (b). The copper wire gauze being a good conductor of heat, spreads the heat in the wire and the gas does not burn above the gauze

above it ignited, the flame does not spread below the gauze. This would not happen if copper is replaced by a bad conductor.

The principle is utilized in making miner's safety lamps (Fig. 4.26). Inside a mine, if there is any explosive gas present, then the copper wire gauze, which covers the lamp, takes up the heat of the flame. The gas, which is just outside the lamp, does not ignite, thus preventing explosion. Miners can detect the presence of such explosive gas by the blue flame and reach a safe

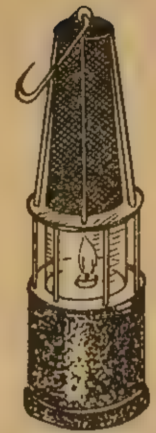


Fig. 4.26. Davy's safety lamp

place before an explosion may take place.

(ii) Thermos flask

A thermos flask used for keeping tea or milk hot or cold for a long time is very common. Different parts of a thermos flask are shown in Fig. 4.27. It consists of a double

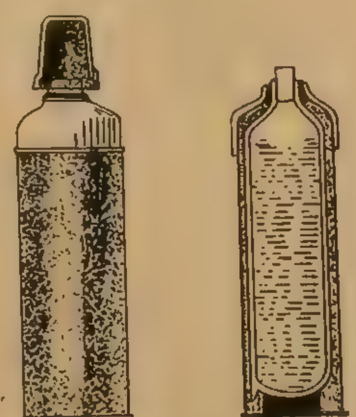


Fig. 4.27. Thermos flask

walled glass bottle. The air from the space between the two walls is

evacuated. The inner surfaces of the walls are polished as mirrors so that the heat radiation is reflected back. The arrangement helps in preventing any loss of heat due to radiation and conduction or convection. The glass bottle is placed in a metallic case as shown in the figure. A rubber or plastic cork is used for closing the bottle. The cap can be used as a small tumbler for drinking tea or any other hot liquid kept in the flask. Thus, any hot liquid remains hot for a long time. The flask can also be used for preventing ice from melting.

Exercise

1. When a mirror is placed in the sun, why does the mirror not become very hot ?
2. Can you give the reason why people prefer using white or light coloured clothes to dark ones in summer ?
3. Explain why the radiators used in central heating system are placed near the floor of the room and not near the ceiling.
4. In a kettle used for boiling water, the handle is covered with a cover made of thin cane strips. Why ?
5. Why in cold countries the water pipes used in buildings are wrapped up with felt ?
6. Ice is kept covered with sawdust, so that it may not melt quickly. Explain.
7. Air is a bad conductor of heat. If a hot substance is left exposed to air it goes on losing heat. Why ?

§ 50. Thermal Expansion of Water

We have already stated that usually liquids expand on heating, and contract on cooling. Water is an exception to this rule. If water at 0°C is heated slowly so that its temperature gradually rises, there is a contraction in volume and the density of water increases; it becomes maximum at 4°C. As the temperature rises above 4°C, its density decreases. In winter, the temperature of water at the bottom of the ponds and lakes does not go below 4°C due to this peculiar behaviour of water. Fishes and other animals can survive in water at the bottom of the lake where the temperature is 4°C while ice is

formed at the top due to freezing. Fig. 4.28 shows the distribution of temperature in a frozen lake.

Fig. 4.28. Vertical temperature distribution in a frozen lake

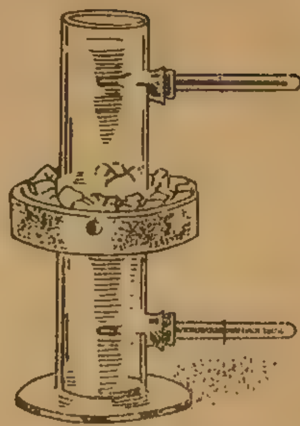


Fig. 4.29. Hope's apparatus

This peculiar behaviour of water can be shown experimentally. A cylindrical vessel is taken as shown in Fig. 4.29. Water at room temperature is poured into the vessel. The trough surrounding the middle part contains freezing mixture, *i.e.*, ice with salt. There are two thermometers to take the readings of the upper and the lower parts respectively. It will be observed that the readings of the two thermometers fall gradually indicating that water is being cooled. After a temperature of 4°C has been reached, the temperature indicated by the lower thermometer remains at 4°C, while the upper one records as much lower temperature. Due to convection small crystals of ice formed in the middle part float to the surface of the water, but the water at the bottom remains at 4°C. It shows that the density of water is maximum at 4°C.

Summary and Conclusions

1. Most of the bodies in any state (solid, liquid, gas), expand on heating and contract on cooling. In the range of 0°C—4°C temperature, water does not expand but contracts on heating.
2. The amount of expansion or contraction depends upon (i) the nature of material and (ii) the amount of change in temperature of the body.
3. For the same amount of change in temperature, the amount of expansion or contraction is different in the three states, more

in the gaseous state, less in the liquid state and least in the solid state.

4. Thermometers, used mostly in physics and technology, are Celsius thermometer. Each such thermometers has two basic points in its scale.

   (a) the 0°C, the temperature at which ice melts under normal atmospheric pressure

   and (b) the 100°C, the temperature at which water boils under normal atmospheric pressure.

5. There are three modes of transfer of heat:
   (i) conduction (ii) convection and (iii) radiation.

6. All metals are good conductors of heat. Cotton, wool and rubber are bad conductors of heat.

7. Convection takes place only in liquids and gases.

8. The amount of heat radiated from a body depends upon its colour. Heat radiated by a black body is more than that by a white body. A good radiator is always a good absorber.

CHAPTER V

Heat and Work

§ 51. Heating of Bodies due to Friction, Forging and Heat Transfer

You have learnt that relative hotness and coldness of a body is known by temperature, which is measured by a thermometer. You have also learnt the different processes such as conduction, convection and radiation by which heat is transferred.

You must have observed that when a knife is sharpened with a grindstone, both of them become hot due to friction between the stone and the metal.

When a meteor comes from outer space and enters into the earth's atmosphere, it does so with a high speed and is heated up by friction to such an extent that it burns up.

In ancient times men used to produce fire by rubbing together two pieces of wood.

The above examples show that bodies get heated by the force of friction developed due to mechanical motion. An experiment is arranged as shown in Fig. 5.1. Fix up a thin brass tube on a stand and pour some ether into it. Close the tube tightly with a cork. After

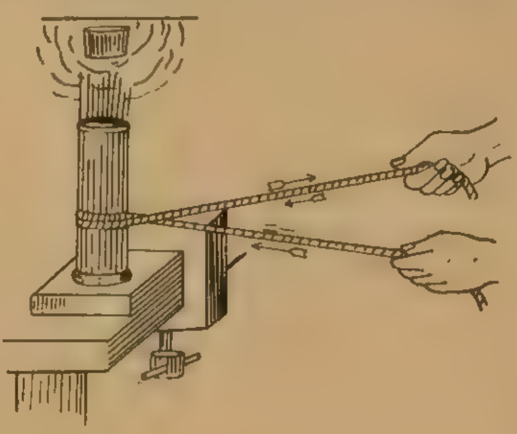


Fig. 5.1. Friction heats a metal tube

winding a string round the tube, pull it backwards and forwards several times. By doing so, the tube becomes heated by friction between the string and the tube. Consequently, the ether starts boiling and the ether vapour pushes out the cork with great force.

This shows that when mechanical

work is done against the force of friction, the body is heated up. Another experiment will also confirm the statement given earlier. Take a thin metal box which has a small side tube and is connected to an alcohol manometer by a rubber tube (Fig. 5.2). The metal box contains some air. When a piece of lead is placed on the metal box and the levels of alcohol in the manometer are the same in both the tubes. The piece of lead is then placed on an anvil and hammered for sometime and then it is again placed on the metal box. The air inside the metal box gets heat from the piece of lead that has become hot after hammering. The manometer indicates an increase in pressure due to expansion of air inside the box.

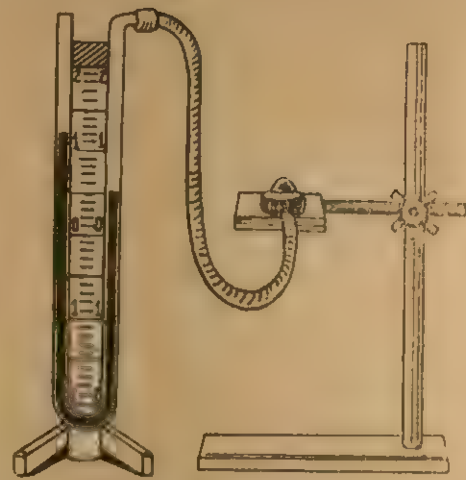


Fig. 5.2. Experiment to show that a piece of lead gets heated on hammering

Experiment

Take a thick glass cylinder with a piece of cotton-wool soaked in ether at its bottom. Hit with a piston. If the piston is pressed inside suddenly, the piece of cotton-wool becomes so hot that it catches fire (Fig. 5.3). These experiments show clearly that a body is heated when some mechanical work is done against the force of friction or resistance.

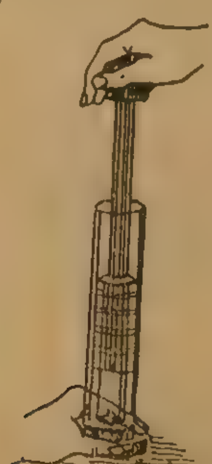


Fig. 5.3. Cotton-wool is ignited due to sudden compression of air

§ 52. Internal Energy of a Body

We have learnt that all bodies consist of molecules.

We also know that all molecules are in constant motion. Gas molecules in their motion collide with each other and also with the walls of the vessel in which the gas is contained. Between two collisions they move in straight lines.

In liquids, the molecules vibrate and move with respect to each other. In solid bodies, the molecules and atoms do not move with respect to each other but vibrate about their mean positions.

Since the molecules are in motion, each must possess kinetic energy. The kinetic energy of a single molecule is, of course, very small. But the total kinetic energy of a large number of molecules in a body is a significant quantity.

We know that two interacting bodies (two bodies exerting a force on each other) also possess potential energy when they are at a certain distance apart. The molecules of a body are separated from each other by small distances and are also interacting with each other. Thus they possess potential energy in addition to their kinetic energy.

The kinetic energy of the molecules does not depend on whether the body as a whole is in motion or at rest. Similarly, the mutual potential energy of the interacting molecules does not depend on whether a body has potential energy with respect to other bodies in the neighbourhood or not.

For instance, the mutual potential energy of the interacting molecules of a body is the same whether the body lies on the ground or it is lifted above so that it possesses a certain amount of potential energy with respect to the ground.

The sum of the kinetic and potential energies of molecules in a body is the internal energy of the body.

The internal energy of the molecules, as we have already explained, does not depend on the motion of the body as a whole or on the position of the body with respect to other bodies. That is why the energy of the molecules of a body is considered as the internal energy of the body.

§ 53. Changes in the Internal Energy of a Body

The internal energy of a body can change. For instance, it has been noticed that the diffusion takes place faster in a liquid when it is heated. This means that when a body is heated, it molecules start

moving faster and their kinetic energy increases.

When a body is cooled, the motion of the molecules decreases, and consequently, their internal energy decreases. A body can do work at the expense of the energy which then decreases.

Let us conduct the following experiment:

Experiment

Air is pumped into a strong glass jar with a little water in it. The jar is closed by means of a cork so that it is air-tight (Fig. 5.4). The jar contains air as well as water vapour. On

Fig. 5.4. Air compressed by pump in a jar pushes out the cork

pumping air into the jar, the air gets slightly heated and a little water evaporates so that the amount of vapour in the jar increases. When the pump is worked for some time so that the pressure inside increases, the cork comes out with a force and mist appears in the jar. Mist is formed due to the tiny drops of water present in the water vapour inside the jar. When the air and vapour inside the jar push the cork out, it does some work and its temperature drops. The decrease in temperature shows that the internal energy of the compressed air and water vapour had been reduced. It can be understood clearly as follows:

The mechanical work done by the water vapour and air is at the expense of its internal energy. It means that in doing the mechanical work, the internal energy decreases. Now the decrease

in the internal energy of air and the water vapour is due to the decrease in its kinetic energy. The decrease in the kinetic energy is due to the fall in its temperature, because the speed of the molecules decreases with the decrease in temperature.

If, after the mist has appeared, the jar is again closed by means of the cork and air is pumped into the jar, the mist will disappear. As a result of the work we have done, the internal energy of the water vapour and air inside the jar has increased and due to the rise in temperature, the drops of mist have turned into vapour.

From the above experiments the following conclusion can be drawn:

The internal energy of a body can be increased by doing work and also by heat transfer from outside without doing work. The amount of internal energy a body receives or loses in the process of heat transfer is called the quantity of heat.

Exercise

1. Why does a cycle pump become hot when air is pumped into the tube ?
2. Temperature is a measure of the level of internal energy. Explain.
3. In a workshop, when a carpenter uses a saw, it becomes hot. Explain.
4. In railway carriages a person whose duty is to check up the axle bearings touches it with his hands. If he finds it too hot, he puts more lubricant. Explain why.
5 The rings of bearings used in machines may melt if sufficient grease is not put in proper time. Why ?

§ 54. Unit of Heat

In this section we shall give you a quantitative idea of measurement of heat.

Perhaps you know that if you burn some logs of wood in a room in order to make the room

warm, it gives out some amount of energy which depends upon the quantity of wood taken. If the quantity of wood is more, the air inside the room will take less time to become warm.

This should make you think that the amount of heat received by the bodies depends on the quality of matter in the body concerned.

Experiment

Take two vessels containing water and let the quantity of water in one vessel be double of the water in the other. Now heat them so that the heating arrangement is the same in both. You will find that in the same period of time, the temperature of the water in the vessel containing more water will be definitely less than that of water in the other.

This experiment shows that more quantity of heat is required for the vessel containing a larger amount of water if we want to heat the water to the same temperature. Let us assume that 1 kg of water is taken in one vessel and 2 kg of water in the other one. If we put the same heating arrangement in both, we will find that 2 kg of water takes twice the amount of time to get heated through the same range of temperature as 1 kg of water does. Thus, the heat required by 2 kg of water will be double of that required by 1 kg of water, if we want to raise their temperatures through 1°C. The amount of heat required to raise the temperature of 1 g of water through 1°C is known as a **calorie.** For measurement of heat calorie is taken as the unit of heat. In engineering, generally, 1,000 calories is taken as the unit of heat and it is called **kilocalorie.** 1 kcal=1,000 cal. Kilocalorie can be defined as the quantity of heat required to raise the temperature of 1 kg of water through 1°C.

§ 55. Specific Heat

You have learnt that 1 cal of heat is required to heat 1 g of water through 1°C. Can you tell what will be the quality of heat required to raise the temperature of 500 g of water through 1°C? The answer is very simple. It will be 500 cal. If you want to heat the same amount, *i.e.*, 500 g of water through 100°C, the heat required will be 50,000

cal or 50 kcal.

You have seen that when we heat a substance its internal energy increases. The above example indicates that the internal energy of the water is increased by 50 Kcal.

So far we have discussed the amount of heat required to raise the temperature of water. Let us now try to study what happens when we heat two different substances at the same range of temperature. Take two vessels as shown in Fig. 5.5. One vessel contains water

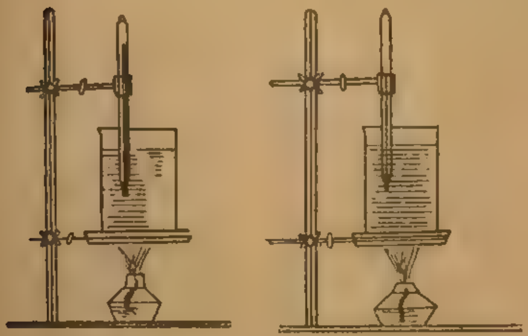


Fig. 5.5. The temperature of equal quantities (mass) of water and vegetable oil under identical conditions increases through different ranges of temperature

while the other vessel contains the same mass of vegetable oil. Heat them separately by two spirit-lamps. Before you start the experiment, the temperatures of both the liquids noted by two thermometers are found to be the same. After some time the temperatures of water and vegetable oil are measured again. The thermometer inside the vegetable oil indicates a higher temperature than that of water, though the amount of heat received by them is the same. If you perform similar experiments with different substances, you will find that the quantity of heat required by them will not be the same. We measure the quantity of heat required to raise the temperature of 1g of a substance through 1°C. You have already seen that the quantity of heat required to raise the temperature of 1g of water through 1°C is a calorie, the unit of heat. The quantity of heat required by 1 kg of a substance to raise its temperature through 1°C is called its **specific heat**

It is expressed in terms of $\frac{\text{cal}}{\text{g degree C}}$. It means that the specific heat of water is one $\frac{\text{cal}}{\text{g degree C}}$.

If the quantity of water taken is expressed in kg and the quantity of heat is expressed in kcal, even then the specific heat of water will be 1, but expressed in $\frac{\text{Kcal}}{\text{kg degree C}}$. Specific heats of some substances expressed in $\frac{\text{cal}}{\text{g degree C}}$ are given below:

Lead	0.03
Copper	0.09
Zinc	0.09
Iron	0.11
Aluminium	0.21
Ice	0.43

Vegetable Oil	0.47
Kerosene	0.51
Alcohol	0.58
Water	1.0

You should note here that due to the use of two units of specific heat $\left(\frac{\text{cal}}{\text{g degree C}} \text{ and } \frac{\text{Kcal}}{\text{kg degree C}}\right)$ the value of specific heat of the same body does not change. It can be seen as follows:

$$1 \frac{\text{Kcal}}{\text{kg degree C}} = 1 \frac{1000 \text{ cal}}{1000 \text{ g degree C}} = 1 \frac{\text{cal}}{\text{g degree C}}$$

We have stated earlier that whenever we heat a substance, its internal energy changes. Keeping the same idea in mind, we can see that the specific heat is a measure of the change in internal energy of one gram of a substance when it is heated through one degree C.

Exercise

1. Take 4 cylinders of equal masses but made of different substances such as aluminium, iron, copper and lead. Heat them first by placing them in boiling water. Then quickly put them in a trough containing paraffin wax as shown in Fig. 5.6. From this experiment how do you find out which

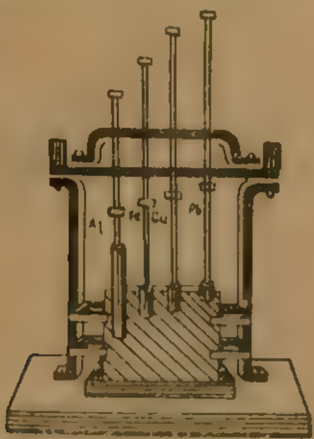


Fig. 5.6. Experiment to show the difference in specific heat of metals

metal has got the highest value of specific heat and which has the lowest ?

§ 56. The Quantity of Heat Gained or Heat Lost by a Body

For practical purposes, it becomes necessary to calculate the exact quantity of heat gained by a body as well as the quantity of heat lost by a body in different processes. We have just now mentioned about the heat lost by the body. It means that when a body is cooled, some heat is lost which is absorbed by the surrounding medium in which the body is placed. It is a reverse process when a body is heated. It then gains heat from the surrounding medium.

For calculating the quantity of heat gained or lost by a body you have to follow the method given below:

Examples

1. A copper sphere of mass 50 g is heated to raise its temperature by 10 C. The specific heat of copper is 0.09 cal/g degree C. Calculate the quantity of heat required in the above process.

To heat 1 g of copper through 1°C the quantity of heat required $= 0.09$ cal

To heat 50 g of copper through 1°C the quantity of heat required $= 50 \times 0.09$ cal

To heat 50 g of copper through 10 C the quantity of heat required $= 50 \times .09 \times 10$ cal $= 45$ cal

2. An iron ball of mass 500 g at temperature 100 C is cooled by placing it in water till its temperature becomes 20 C. Calculate the quantity of heat given off by the iron ball if the specific heat of iron is $0.11 \cdot \frac{\text{cal}}{\text{g degree C}}$.

Here, fall in temperatur of the iron ball $= 100$ C—20 C $= 80$ C

∵ Quantity of heat given off when 500g of iron cools through 1°C $= 0.11$ cal.

∴ Quantity of heat given off when 500 g of iron cools through 1°C $= 0.11 \times 500$ cal

∴ Quantity of heat given off when 500 g of iron cools through 80° $= 0.11 \times 500 \times 80$ cal $= 4400$ cal

From these examples, it is quite clear that to calculate the quantity of heat gained or lost by bodies, we multiply the masses of these bodies by both the specific heat and by the

difference in temperature. If q is the quantity of heat gained or lost in the process, m the mass of the body and s the specific heat of the substance, then

$$\boxed{q = s \times m\,(t^\circ_2 - t^\circ_1)\ldots\text{for heat gained}}$$

and,

$$\boxed{q = s \times m\,(t^\circ_1 - t^\circ_2)\ldots\text{for heat lost}}$$

Exercise

1. The specific heat of lead is 0.09 cal/g degree C; explain what it means.
2. 2 kg of water is heated through 5°C in one vessel and 1 kg of water is heated through 10°C in another vessel. Do you think the quantities of heat required will be the same or different ?
3. Take two pieces of copper and aluminium having equal mass and heat them through a small range of temperature. Which one do you think will require more heat ?
4. Calculate the number of kcal required to raise the temperature of 0.1 kg. of brass from 25°C to 75°C. The specific heat of brass is 0.09 $\dfrac{\text{K cal}}{\text{kg degree}}$
5. The specific heat of alcohol is 0.58 cal/g degree C, that of kerosene =0.45 cal/g degree C, of vegetable oil=0.47 cal/g degree C, and of water = 1.0 cal/g degree C. If we take the same quantity of these liquids and want to heat them, which one do you think will be heated first if other conditions remain the same ?
6. An aluminium vessel of mass of 300 g containing 1 litre of water is heated. If you want to raise the temperature of water from 15°C to 20°C, calculate the amount of heat required.

§ 57. Laboratory Work —

Name: Compare the quantities of heat gained and lost in mixing the cold and hot water.

Apparatus and materials: Two glasses, measuring glass, thermometer.

Procedure: Take 50g of hot water in one glass and the same amount of cold water in another.

1. Measure the temperature of water in both the glasses.

2. Pour the cold water from one glass into the other. Stir and note down the temperature of the mixture.

3. Find out the quantity of heat given out by the hot water when it cools down to the temperature of the mixture. Calculate the quantity of heat received by the cold water when it is heated up to the same temperature, i.e., the temperature of the mixture. Enter the results of the experiment in the following table.

4. Repeat the experiment by using different quantities of water.

5. Compare the quantity of heat given off by the hot water with the quantity of heat received by the cold water.

6. Mention the possible sources of error in your observations and what precautions will you take for that.

Mass of hot water m_2	*Initial temperature of hot water* t_2	*Temperature of mixture* t	*Quantity of heat given up by hot water* Q_2	*Mass of cold water* m_1	*Initial temperature of cold water* t_1	*Quantity of heat received by cold water* Q_1

§ 58. The Energy of Fuel

It becomes necessary for an engineer to know exactly how much quantity of heat is produced when a definite quantity of fuel is burnt. This is especially important when a person is engaged in designing a machine.

You know that we burn coal for producing energy for domestic purposes. Similarly, in industry the main sources of energy are coal, oil, etc. The quantity of heat obtained, when we burn 1 kg of fuel completely, is called its **heat of combustion.** This is expressed in Kcal/kg. This quantity is determined experimentally and the results of such experiments are given in the following table to give you some idea of how much quantity of heat is obtained from various fuels commonly used.

To calculate the quantity of heat obtained by burning any fuel you are required to know two quantities,

(1) the mass of the fuel and (2) the heat of combustion of the fuel. The product of these two quantities gives the quantity of heat produced by burning the fuel. If the heat of combustion is denoted by Q, the the mass of the burnt fuel by m and the total quantity of heat produced by burning the fuel by q, we have,

$$\boxed{q = Q \times m}$$

Heat of combustion of some fuels (in kcal/kg)

Fire wood	about	3,000
Coal		7,000
Charcoal		8,000
Gas		8,500
Diesel Oil		10,500
Petrol		11,000
Kerosene		11,000

Exercise

1. What do you understand by the term 'heat of combustion' of a fuel ? In what unit is it expressed ?
2. How much heat is produced by burning 10 kg of charcoal ?
3. If you want to obtain 44,000 kcal of heat, how much dry wood you must burn ?
4. What is the amount of kerosene which, on complete burning, will produce 45,000 Kcal of heat ?

§ 59. How to Calculate the Thermal Efficiency

Now you know that by burning the required quantity of fuel we can produce whatever heat we require. When we want to heat some water in a kettle and the necessary heat we get by burning some quantity of fire wood, the heat produced is also used up in heating the surrounding medium and only a portion of it is actually used for heating the water in the kettle

The same thing is applicable to other fuels used for different purposes. Whatever may be the source of heating arrangement, the fraction of energy usefully utilized for a definite purpose out of the total amount of energy supplied to it, is called the **thermal efficiency**.

You have learnt how to calculate the efficiency of a machine discussed in Chapter III and how it is expressed in percentage.

You are using a kerosene stove for heating some water. Suppose the total heat produced by the complete combustion of kerosene is 100

kcal and only 40 kcal of heat is used for actual heating of water.

Then the thermal efficiency is equal to $\frac{q_u}{q_t}$ where q_u is the quantity of heat utilized for the actual purpose and q_t is the total heat produced by the stove. Thermal efficiency may be represented as:

$$\boxed{E = \frac{q_u}{q_t} \times 100\%}$$

Exercise

1. Calculate the efficiency of a kerosene stove which uses 50 kg of kerosene to heat 4 litres of water from 50° to 100°C.
2. The thermal efficiency of a stove is 30 per cent. How much kerosene should be used for boiling 2 litres of water when the initial temperature of water is 20°C?

§ 60. Laboratory Work

Name: To find out the Thermal efficiency.

Apparatus and materials:

Spirit-lamp, thermometer, scales, water, measuring glass, glass, vessel, holder, etc.

Procedure:

1. Take 150–200 g of water in a vessel and note down its temperature.

2. Determine by weighing the mass of the spirit-lamp with spirit before using it for heating.

3. Heat the water to raise its temperature in the range of 50°C – 60°C, and measure its temperature.

4. Determine by weighing the mass of the spirit-lamp at the end of the experiment after it is used for heating water.

5. Enter your observations in the following table.

6. Calculate the thermal efficiency of this spirit-lamp from your experimental observations.

Spirit				Water					
Initial mass of burner with spirit (m_1)	Mass of burner after experiment (m_2)	Mass of burnt spirit ($m=m_1$-m_2)	Quantity of heat produced by burnt spirit ($q_t=Q\times m$)	Mass of water (m_3)	Initial temperature of water (t_1°C)	Final temperature of water (t_2°C)	Quantity of heat received by water $q_u=S\times m_3$ (t_2°C-t_1°C)	Efficiency $E=\frac{q_u}{q_t}\times 100\%$

§ 61. Relation between Unit of Work and the Thermal Unit

We have seen in the experiment mentioned in section 50 that the air inside the cylinder becomes hot when it is compressed. Similarly, when we hammer a piece of lead it becomes hot. These experiments show that the internal energy of a system increases when some mechanical work is done. If instead of hammering the piece of lead or compressing the gas inside the cylinder, we directly heat them, we can produce the same effect. In other words, the temperature of the air inside the cylinder and the temperature of the lead can be raised without doing any mechanical work. We have stated earlier that the internal energy of a system increases whenever we heat them. It shows that there is some relationship between the mechanical work done and the quantity of heat produced.

A British scientist, named James Joule, first experimentally determined the relationship between the mechanical work and the heat produced. You will learn about it later on. He determined how much work must be done on a body to increase its internal energy by the same amount as it is increased when 1 kcal of heat is given to it.

From the experimental work of Joule, it was found that 4,184.6 joule of work is necessary to produce 1 kcal of heat.

4,184.6 joule=1 kcal=1000 cal. Thus, we may write.

427 kgwtm=1 kcl

4.18 Joules=1 cal

1 Joule =0.24 cal

Example

1. Calculate the heat produced and express the heat in kcal when 20,923 joule work is done. We know 4,184.6 joules of work is

equivalent to 1 kcal of heat. Therefore 1 joule work is equivalet to

$$\frac{1}{4{,}184.6} \text{ kcal}$$

20,923 joules work is equivalent to

$$\frac{20{,}923}{4{,}184.6} \text{ kcal} = 5 \text{ kcal}$$

Calculate the amount to work in kgwtm which is equivalent to 10 kcal of heat.

$\because$ 1 kcal = 427 kgwtm

$\therefore$ 10 kcal = 427 kgwtm × 10

= 4270 kgwtm

§ 62. Law of Conservation and Transformation of Energy

(*i*) When a body is falling freely so that the friction of air is negligible, its potential energy is transformed into kinetic energy and when it strikes the ground it is transformed into the internal energy of the body and the ground because the temperature rises.

(*ii*) When a meteor comes from the outer space, its potential energy is transformed into kinetic energy when it enters the earth's atmosphere and the speed is reduced due to the friction of the air so that the amount of kinetic energy decreases but at the same time the internal energy of the meteor and the air increases, because, due to friction, the temperature of the meteor increases.

(*iii*) If we have water in two vessels at different temperatures and then mix them together, the mixture will be at some intermediate temperature within a short time. Water at the higher temperature loses some amount of it and at the same time the cold water gains heat and the experiment shows that the amount of interal energy lost by the hot water is equal to the gain in the internal energy by the cold water.

(*iv*) When fuel is burnt in the boiler of a steam engine, the energy of the fuel is transformed into the energy of the steam. In turn, in the steam engine, the internal energy of the steam is turned into the mechanical energy of the motion of the piston and so on.

The above examples show that in nature and in all types of machines, constant change of energy takes place but the total amount of energy in the system always remains the same. This is known as the **law of conservation and transformation of energy** which states that **in all phenomena taking place in nature energy can neither be created nor destroyed; it can only be transformed from one form into another.**

§ 63. Sun—The Main Source of Energy on Earth

We have told you that for producing heat we burn some fuel such as wood, charcoal, coal and kerosene, etc. But the main source of

heat and light on earth is the sun. When the sun's light falls on the earth it is transformed into heat and energy in plants. Coal which is mostly used for producing heat energy is nothing but deposition of charcoal. Large areas of the world were once covered by forest and the remains of this forest were deposited as coal.

We have stated earlier in Chapter IV that how wind is produced by the constant heating of air in the earth's atmosphere. By constant evaporation of the water surface moisture is carried to a great height and cloud is formed. This evaporation is a continuous process and is taking place due to the heat received from the sun. Plants use solar energy for their growth. Animals feed on plants or other animals that feed on plants. Thus, the main saurce of energy for animals as well as human beings is the solar energy.

The amount of solar radiation falling on the earth's surface can be determined experimentally. We get approximately two calories of heat per minute on each sq cm of the earth's surface when sun's rays fall perpendicularly. If it is expressed in power, it comes to approximately 1.4 kw per sq metre on the surface of the earth. You will learn later on about the atomic energy and its nature as a powerful source of energy on earth.

Summary and Conclusions

1. Heating of a body is caused either by transfer of heat to the body or by doing mechanical work on it.
2. Internal energy of a body consists of (i) kinetic and (ii) potential energies of the molecules composing the body.
3. On being heated, the internal energy of a body increases due to the increase in the kinetic energy of its molecules. This increase in kinetic energy is indicated by the rise in temperature of the body.
4. Due to the fall in temperature on cooling, the decrease in the kinetic energy of the molecules of a body causes decrease in the internal energy of the body.
5. Specific heat of a body is the quantity of heat required to raise the temperature of its 1 kg mass by 1° C.
6. Specific heat is measured in either

   cal/g degree or k cal/kg degree

7. The quantity of heat, which changes the temperature of a definite mass of the body from $t°_1C$ to $t°_2C$, is calculated with the help of the following formula.

$$q = S \times m\ (t°_2 - t°_1) \qquad \text{(in case of heating of the body)}$$

$$q = S \times m\ (t°_1 - t°_2) \qquad \text{(in case of cooling of the body)}$$

Where S is the specific heat and m is the mass of the body.

8. The heat of combustion of a fuel is the quantity of heat produced by burning completely 1 kg of fuel. The heat of combustion of a fuel is measured either in

cal/g or k cal/kg

9. The quantity of heat produced by complete burning of a certain quantity of fuel is calculated by the following formula.

$$q = Q \times m$$

Where Q is the heat of combustion and m is the mass of the fuel burnt completely.

10. The thermal efficiency of a heater is measured by the following formula.

$$E = \frac{q_u}{q} \times 100\%$$

Where q_u = useful quantity of heat
q_t = total quantity of heat

11. Relation between units of mechanical work and the quantity of heat is as follows:

427 kgwtm—1 K cal
4.18 J —1 cal

12. *The law of conservation and transformation of energy:* In all phenomena taking place in nature, the energy can neither be created nor destroyed. It can only be transformed from one form into another.

Transition of Substances From One Aggregate State Into Another

§ 64. Crystalline And Amorphous Substances

You know that when water starts boiling, it produces steam. On the other hand if the temperature of the water is lowered up to 0°C so that it freezes, then ice is formed. This shows that matter can exist in three different states: (a) solid, (b) liquid and (c) gas (Fig. 6.1).

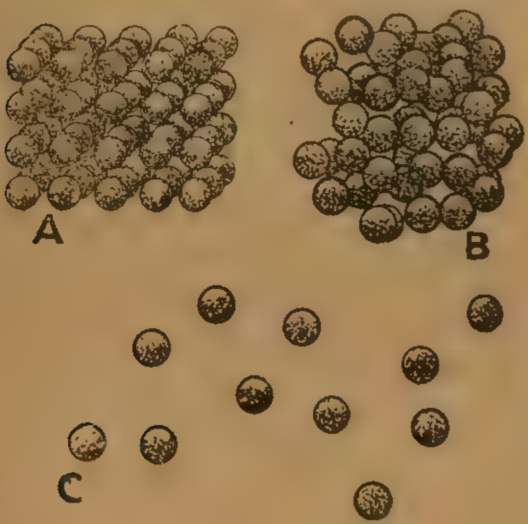


Fig. 6.1. Molecular arrangements in three states of matter

Solid

A solid body can be of two different types: crystalline and amorphous. The word crystal comes from a Greek word meaning clear ice. When snow-flakes are collected and kept in a piece of dark cloth and are closely observed with a magnifying glass, they will be found to possess regular shapes. We have mentioned that in solids the atoms vibrate. The fixed positions about which they vibrate are arranged in an orderly way.

The orderliness of atoms in solids is its distinctive feature and this property distinguishes it from liquids.

All metals, which you see everyday and which are used in machines and other household articles, are made of different crystalline substances. If you observe them just with your naked eye you cannot consider them as crystalline substances. But all metals and most

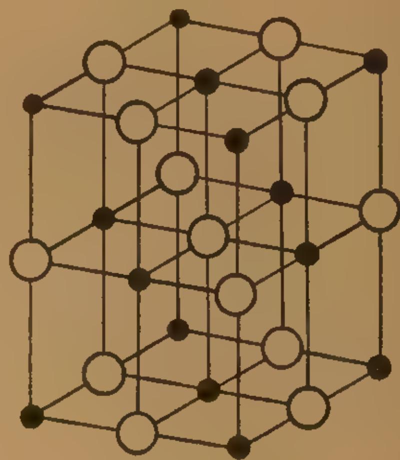
minerals are crystalline. When broken pieces of metals are examined under a microscope, the crystalline structure can be observed. It may be mentioned here that large crystals do not suddenly come into existence but they slowly grow. Snow-flakes grow directly from moist air (Fig. 6.2).

Fig. 6.2. Crystals of snow-flakes

The theory of structure of bodies shows that when atoms are arranged in an orderly way so that the order is repeated regularly, the substance is said to be crystalline.

The experimental and theoretical study of crystals has shown that different types of crystalline substances have different forms of crystals. For example, we give you some forms of crystalline substances such as kitchen salt (1), diamond (2) and ice (3). (Figs. 6.3 and 6.4).

Fig. 6.3. External forms of some crystalline substances



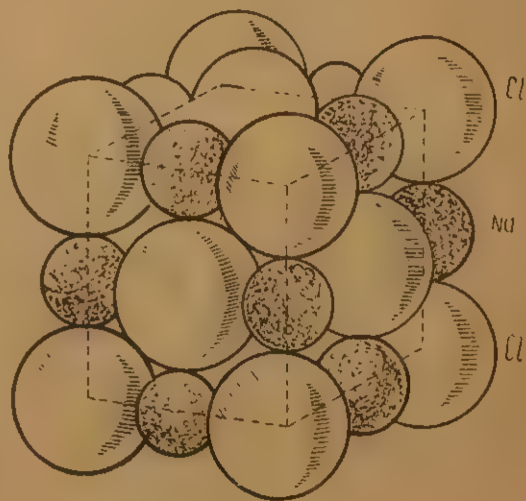


Fig. 6.4 The NaCl crystal molecular formula

Some solid bodies are known as amorphous substances. For example, substances such as glass, various resins, paraffin wax, are amorphous substances. Here, in these substances, the molecules are not arranged in an orderly way. Because these

bodies are different in nature from crystalline bodies, their properties are also different from the properties of the crystalline substances.

§ 65. Melting and Crystallization of Crystalline Substances

When a substance changes from the crystalline body to the liquid state, the process is called melting. For example, ice melts at 0°C at normal atmospheric pressure, *i.e.*, 760 mm of pressure. The temperature at which a crystalline body melts is known as its melting point. The melting points of different substances are different. Tin and lead can be melted easily but for melting iron or steel we have to heat them for a long time. From practical exeprience it has been found that iron melts at about 1500°C.

The temperature at which a crystalline body changes into a liquid at normal atmospheric pressure is called its melting point.

The temperature at which the process of crystallization takes place at normal atmospheric pressure is called the point of crystallization.

Experiment shows that crystalline substances crystallize at the same temperature at which they melt. For example, water crystallizes (and ice melts) at 0°C. Pure iron melts and crystallizes at about 1530°C and so on.

If you want to understand the process of melting, you can conduct a simple experiment.

Experiment

Take some crystalline substance such as naphthalene in a vessel and heat it. Measure the temperature at regular intervals. The result of the experiment is given in the diagram (Fig. 6.5); the first part shows the process of melting and the second part shows the process of crystallization. If you observe it carefully, you will find that first the temperature rises till it reaches the temperature of melting point, *i.e.*, 80 C. At 80°C the naphthalene begins to melt and the temperature remains constant during the process of melting till the quantity of nephthalene melts completely. During the process of melting when the temperature remains constant, the nephthalene remains in both the states, partly in solid state and partly in liquid state. Then the temperature begins to rise and touches 90°C. When it is allowed to cool down again, it crystallizes at 80°C and the temperature remains constant till the whole of the liquid nephthalene is turned into crystalline. Here, again, during the process of crystallization at constant temperature, it exists in both the states,

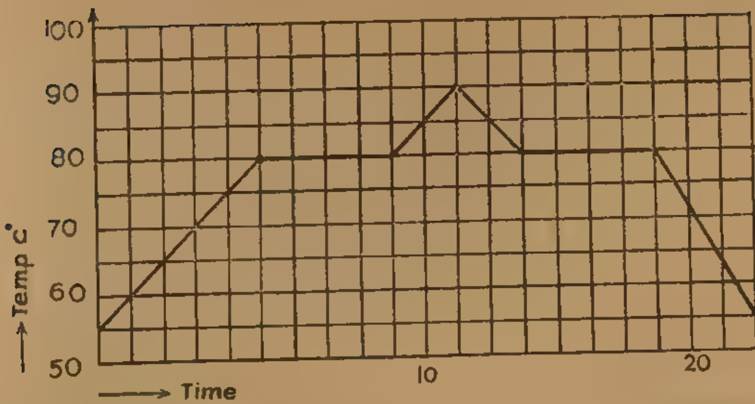


Fig. 6.5. Graph showing the melting and crystallization of naphthalene

partly in crystalline state and partly in liquid state. The temperature of the solid naphthalene drops further only after the process of crystallization is complete.

Similarly, experiments can be performed with other crystalline substances in place of naphthalene. The only difference will be in the temperature of melting of each substance.

From the above, experiment you will find that the melting point and the temperature at which a substance crystallizes will be the same for the same substance. But it is different for different substances. The temperature remains constant during the process of melting as well as crystallization. Thus we can summarize as under:

(1) Crystalline substances melt and crystallize at the same definite temperature characteristic of each substance.

(2) The melting point and crystallization point of different crystalline substances are different.

(3) During the process of melting and crystallization, the temperature of the crystalline substance does not change.

The following table gives the melting points of some substances:

Melting points of substances in °C

Hydrogen	—259	Zinc	419
Oxygen	—219	Aluminium	660
Nitrogen	—210	Gold	1063
Alcohol	—114	Copper	1083
Mercury	— 39	Platinum	1773
Ice	— 0		
Tin	—232	Tungsten	3370
Lead	—327		

Castings of different metals are made by pouring the molten matter into different moulds and allowing them to cool. This is mostly utilized in foundry works. This principle is now also utilized for making stone castings. Molten stone is used for making pipes, the base plates of machines such as lathes, etc. We have stated earlier that the molecules and atoms in crystals are arranged in a regular form. The crystals of a substance have a definite form of their own and in solids they are always closely held together. In liquids the molecules move about freely but due to the force acting on the surface of the liquid they find it difficult to escape from the liquid surface.

When a solid is heated the internal energy of the solid increases and alters the regular atomic arrangement in the crystals. When the substance melts and turns into a liquid, the regular atomic arrangement is disturbed. We have stated earlier that large crystals are not produced suddenly but grow slowly. It means that when the temperature of the liquid becomes the temperature of the crystallization, small crystals are formed first and then as the cooling is continued, the crystals grow in size till the entire liquid is crystallized.

There is no temperature of crystallization for amorphous substances, *i.e.*, they do not have definite melting points and temperatures of crystallization. When we heat amorphous substances they become softer and softer until they turn into a liquid. In amorphous substances, if the temperature is lowered so that they become solid, they gradually turn from liquid to solid but no crystals are formed. Here the molecules remain in their irregular forms as in a liquid. What happens here is that the substance grows thicker and thicker, showing that the molecules do not move so freely as in the liquid state till the whole thing is solidified. Solid amorphous substances are merely thick liquids.

Exercise

1. If you want to measure the outside temperature in very cold countries, what type of thermometer will you use, an alcohol or a mercury thermometer ?
2. The melting point of tin is 232°C. If this is thrown in molten lead, do you think it will melt ?
3. Can you use an aluminium saucepan for melting zinc ?

§ 66. Laboratory Work

Observation of the Heating and Melting of Naphthalene

Apparatus and material : A Wide test-tube, thermometer, naphthalene, beaker, spirit-lamp.

Procedure :

1. Put the test-tube with the naphthalene and the thermometer into a beaker containing water and heat it over a burner on a small flame (Fig. 6.6).

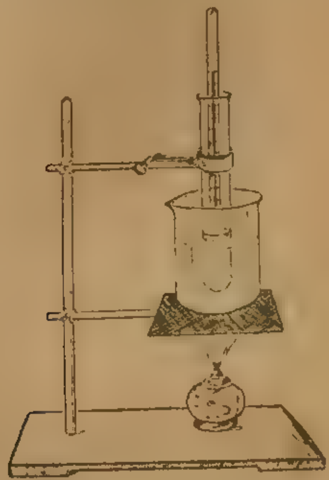


Fig. 6.6. Apparatus for determining the melting point of naphthalene

2. When the temperature of the naphthalene has reached 55°C, take the temperature of the naphthalene every minute and note it down in your exercise book. Heat the naphthalene to 90°C, after which remove it from the hot water and let it cool, noting the temperature every minute until it reaches 60°C.

3. Draw a graph between the temperature of naphthalene and the time of heating (like the one shown in Fig. 6.5).

4. Mark on the graph the temperature of melting and the temperature of crystallization. Compare them. What conclusion can be drawn from this comparison ?

5. Watch the temperature of the naphthalene during the processes of melting and crystallization.

6. Name and mark on the graph the state of naphthalene when its temperature changes.

7. Name the states in which the naphthalene was during the processes of melting and crystallization.

§ 67. Heat of Fusion

Experiment

Take a large beaker with small pieces of ice crystals and put a thermometer inside it. The thermometer reads 0°C. Heat it by a spirit-lamp and go on stirring it so that the temperature

remains uniform. You will find that as heating is continued, the ice starts melting and during the process of melting the temperature remains constant till the whole of the ice is melted.

If the water is now continuously cooled, its temperature gradually falls, until at a certain temperature the water begins to solidify and again ice is formed. As the process is continued more and more of the water solidifies, but the temperature remains the same till the whole mass of the water gets solidified.

You have observed in the experiment with naphthalene that when it is heated it starts melting and during the process of melting the temperature remains constant.

When the total quantity of naphthalene melts entirely and the spirit-lamp is removed, then it starts solidifying and during the process of solidification, again the temperature remains constant.

Here you see that to melt a crystalline body, we add some quantity of heat to the body. As the temperature of the body does not increase during the process of melting, it indicates that the quantity of heat added does not increase the kinetic energy of the molecules of the body. You also know that the internal energy of a body is equal to the sum of the kinetic and potential energies of all the molecules of the body. So it means that the quantity of heat supplied during the process of melting is utilized increasing the potential energy of the molecules of the body.

The spirit-lamp, which is used for heating in both the experiments with ice and naphthalene, was not removed when the crystals of naphthalene and ice started melting. It means that the heat received by the crystals of naphthalene and ice was utilized for breaking the regular shapes of the crystals till they are changed completely from the solid to the liquid state.

The quantity of heat which is utilized for changing one kilogramme mass of a substance from a solid to a liquid state at its melting point is called the heat of fusion.

If an experiment is conducted with ice, it shows that to change 1 gram of ice to 1 gram of water at 0°C, 80 calories of heat are required.

To change 1 kg of ice to water at 0°C the heat required will be 80 kcal.

To calculate the quantity of heat required to melt a certain quantity of solid, it is needed to know the two quantities (i) the mass of the solid and (ii) the heat of fusion of the solid. The product of these two quantities is equal to the quantity of heat required to melt the solid. If we denote the heat of fusion by l, the mass of the solid by m, the

quantity of heat required to melt the solid completely by q, we have,

$$\boxed{q = l \times m}$$

The latent heat of fusion of some substances is given below :

Heat of fusion in cal/kg or kcal/kg

Ice	80
Iron	66
Copper	42
Lead	6.3
Mercury	2.8

We have stated earlier that whenever we heat a substance, its internal energy changes. You have learnt now that when 1g of ice is changed to 1g of water at 0°C, 80 cal of heat is required.. It shows that the internal energy of 1g of water is more than that of 1g of ice.

This shows that the heat of fusion of ice indicates by how much the internal energy of a substance increases when it changes from the solid to the liquid state without any change in temperature.

We have seen earlier in the experiment with naphthalene that, when liquid naphthalene is cooled, the thermometer indicates a fall in temperature. When it reaches the temperature of crystallization, the liquid is solidified gradually. When crystallization starts the temperature remains constant. The internal energy of liquid naphthalene is given off. We have seen that heating means increase in internal energy, then naturally cooling means a loss in internal energy. The loss of internal energy in liquid naphthalene when it is cooled is made up by the internal energy of the liquid naphthalene in the process of crystallization. Consequently, the thermometer does not indicate any change in temperature during crystallization.

When the process is completed the temperature begins to fall again.

This shows that a substance gives off exactly the same amount of heat in the process of crystallization that it requires for melting.

In other words, we can say that the same quantity of heat is absorbed by a substance when it melts as is given off when it is solidified. In cold countries, when ice melts during spring, the areas surrounding big lakes and rivers often indicate a sudden fall in temperature. The heat required for melting the ice is absorbed from the surrounding objects, as a result of which there is a sudden fall in temperature.

Similarly, when winter begins and the water freezes, these areas give off an amount of heat, which is the same as the latent heat of fusion and you do not find thick frosts in these areas, because the heat given off prevents the formation of frosts.

Exercise

1. Why the quantity of heat required for changing 1 g of a substance from solid to liquid state at its melting point does not produce any change in temperature?
2. Calculate the amount of heat required to melt 5 kg of ice at 0°C.
3. A piece of 10 g of lead is taken. The initial temperature of the lead is 27°C. Calculate the amount of heat required to melt it if the heat of fusion of lead is taken approximately 6 cal/g and the melting point of lead is 327°C.
4. If melting ice is brought in a room where the temperature is 0°C, do you think that the ice will melt ?
5. When a substance crystallizes, it gives off the same quantity of heat, which it absorbs when it melts. Explain.
6. Take two identical tin vessels and take 200 g of ice in one and 200 g of water in the other. Heat them till they start boiling. Do you think they will take the same time or different ?
7. If 20 g of ice at 0°C is dropped into 90 g of water at 30°C contained in a glass beaker and stirred for sometime, the temperature of water becomes 10°C. Calculate the heat of fusion of ice.

§ 68. Alloys and Their Applications

You have learnt now that the melting point of a crystalline substance is a definite temperature at which a substance changes from the crystal to the liquid state.

If a substance is pure it melts at that definite temperature, but if there is any impurity mixed with the substance, it always lowers the melting point.

Experimental results have shown that the melting point of a pure substance, say a metal like iron or tin is always higher than the melting point of a substance which is made of two or three metals mixed in different proportions.

The determination of the melting point of a substance is thus a convenient method of testing the purity of a substance. Sometimes it becomes necessary to mix two or more metals for various purposes. These are known as **alloys.**

Perhaps you have heard about the element carbon in your chemistry lessons. Different fuels such as coal, charcoal, etc. are nothing but impure carbon. Diamond which is a precious stone is also a form of carbon. Because it is very hard, it is used for making cutting tools and can be made in the laboratory by heating carbon under high pressure.

When carbon is heated to a very high temperature and then diffused into iron, the iron is transformed into steel. This process increases the hardness of iron, so that it can be used for making different tools such as drills, cutters, screw taps, etc.

You will be surprised to know that steel which is a very common substance now was manufactured in very small quantities until about the middle of the eighteenth century.

Now alloys are used for various practical purposes and they have wide applications especially in the field of engineering.

You may have seen knives, forks, spoons and other kitchen utensils as well as surgical instruments, made of a particular type of steel known as stainless steel. Here, suitable quantities of different metals such as chromium, nickel, etc., are mixed with iron so that it is harder than ordinary steel. It does not rust and is not attacked by acids.

In this way we get different types of steel such as extra hard steel, stainless steel, heat resistant steel, etc.

An alloy known as duralumin is generally used for making different parts of aeroplanes, ships and motor cars. It is chosen because it is very light and at the same time very strong and durable.

Here copper, manganese and magnesium are mixed in very small quantities with aluminium. The melting point of this alloys is 650°C.

We have been discussing about alloys which are known especially for their strength and hardness. Sometimes it is necessary to make alloys that are very soft and melt at a very low temperature.

An alloy made of bismuth, tin and lead is very soft. This alloy is especially used as safety devices in boilers.

When the level of water drops below the normal level, then these safety plugs are heated up and they melt. This prevents an explosion in the boiler.

Fuse wires are commonly used in electrical circuits so that when there is a rise in temperature due to heavy current flowing in the circuit, it melts and prevents further damage to costly electrical parts. They are made of an alloy of tin and lead and have very low melting points. You will learn about them in detail later on.

Perhaps you have noticed people getting tinned vessels used in the kitchen as utensils. If you watch the tinning process, you will find that a particular alloy is used for the purpose. It is called solder. It consists of an alloy of lead and tin.

In different machines, especially in the shafts of motor-cars and tractor engines, a lining, made of a very soft alloy, is used. When the temperature is very high due to insufficient lubrication of these parts, the part made of the alloy melts, thus preventing damage to the shaft.

§ 69. Evaporation

We have already discussed about the change of a substance from the crystalline to the liquid state and also from the liquid state to the crystalline state. There is a different process by which a liquid can change to the gaseous state and this process is known as **vaporization.** This process can take place in two different ways, evaporation and boiling.

First, we shall study the process of evaporation. When vaporization takes place at all temperatures from the surface of the liquid, it is called **evaporation.** It is a slower process of vaporization compared to boiling. **Factors determining evaporation depend on : (i) The area of the exposed surface.**

If you take two vessels having different areas of the surface and take a liquid at the same temperature in these two vessels and leave them for sometime, you will find that the liquid in the vessel with greater area of exposed surface is less than the liquid in the other vessel.

This experiment shows that the rate of evaporation depends on the area of the exposed surface.

The following examples will also indicate the same thing:

(*a*) Wet clothes dry up more quickly if they are not folded but spread out in the sun.

(*b*) Hot drink from a cup is sometimes poured from the cup into the saucer so that it cools more quickly.

(*c*) When a drop of ink falls on a blotting paper, it spreads over a large area and dries quickly but on an ordinary paper it does not spread and therefore does not dry quickly.

(ii) The rate of evaporation depends on the temperature of the liquids.

If you take two exactly similar vessels containing the same liquid and the liquid in one vessel is at a higher temperature than in the other, you will observe after sometime that the mass of the liquid at

the higher temperature is less than the mass of the liquid in the other vessel. From this we can conclude that the rate of evaporation depends on the temperature of the liquid and is high at a high temperature.

For example, if you have some water in the street, it dries up more quickly in summer than in winter. Clothes dry up more quickly when the temperature of the air is high. When the temperature is high, bodies dry up more quickly after swimming.

(iii) The rate of evaporation depends on the nature of the liquid.

If you have two similar vessels containing different liquids at the same temperature, you will notice after sometime that mass of liquid in one vessel is less than that in the other.

For example, if you have water in one vessel and ether in the other, at the same temperature, you will find that ether evaporates more quickly than water.

Perhaps you have noticed that you get the smell of petrol in air near a petrol-pump, because it is highly volatile. If clothes are left in a closed room after dry-cleaning, one gets the smell of petroleum when one enters the room.

(iv) The rate of evaporation depends on whether it takes place in closed vessel or in an open one.

Take an equal amount of water in two similar vessels and cover one of them with a bell-jar. After sometime you will notice that the water in the open vessel has evaporated more quickly than that in the covered bell-jar.

§ 70. Explanation of the Process of Evaporation and Condensation

We have stated that evaporation is a gradual change from the liquid to the gaseous state. How evaporation takes place can be explained in the following way.

In evaporation, molecules go out from the surface of the liquid and all these molecules produce the vapour of the same liquid.

You know that between all molecules of the liquid there is a force of attraction and the magnitude of the force of attraction is quite large. So to change from the liquid to the gaseous state the molecules must overcome the force of attraction.

The molecules which are inside the liquid cannot go out from the liquid. Consider one particular molecule inside the liquid. Fig. 6.7 shows that on all sides of this molecule there are a number of molecules which attract it with the same force in different directions.

Only the molecules which are lying on the surface of the liquid can escape from the liquid. From

Fig. 6.7 we can see that on all the molecules lying on the surface of

Fig. 6.7. Mechanism of evaporation of water from the liquid surface

the liquid, the molecules which lie inside the liquid exert a force of attraction.

The molecules on the surface of the liquid have to overcome this force of attraction in order to escape from the liquid surface.

Therefore all molecules which lie on the surface cannot escape. The molecules must have sufficient kinetic energy to overcome the force of attraction by the molecules inside the liquid. How can the molecules which lie on the surface of the liquid receive the necessary amount of kinetic energy?

You know that all molecules of the liquid are in constant motion and they collide with each other. Sometimes, molecules due to frequent collisions attain greater speed and have more kinetic energy. Molecules with larger values of kinetic energy overcome the force of attraction and escape from the surface of the liquid and produce vapour of the liquid.

From this we can conclude that **for the process of evaporation the molecules must possess sufficient kinetic energy.**

This amount of energy is taken from the internal energy of the liquid. So, during the process of evaporation, the internal energy of the evaporating liquid is reduced and as a result, the temperature of the evaporating liquid falls.

In condensation which is the reverse process of evaporation, the vapour gives out energy when it is changed into liquid.

If you have 1 g of water vapour at the temperature of evaporation, we can say that the internal energy is more than the internal energy of 1 g of water at the same temperature by an amount which is equal to the quantity used in the process of evaporation. Thus, internal energy is given out when 1 g of water vapour is changed into water. The conclusion can be drawn by suitable examples:

(*a*) After swimming when one comes out of the pond, one feels cold due to evaporation.

(*b*) If you take a little volatile liquid such as ether in your hand, you feel cold; it is due to evaporation.

(*c*) If you take water in a beaker and put a thermometer in it and allow some steam to condense inside the water, the temperature of water will increase because during condensation the steam gives off energy.

We have observed that the rate of evaporation depends on the area of the surface. This can now be easily understood. If the area is more the number of molecules can escape from the liquid.

You know that the rate of evaporation depends on the temperature of the liquid. This can also be easily explained. When the temperature is high, the speed of the molecules is also high, so that their kinetic energy also is high and there is a large number of molecules with sufficient kinetic energy to escape from the surface.

You know that the rate of evaporation depends on the property of the liquids. You can understand it because in different liquids, the magnitude of the force of attraction between different molecules is different. Evaporation will be easier in those liquids in which this force is smaller.

The rate of evaporation depends on the conditions of the process of evaporation. If it takes place inside a closed vessel, two processess of evaporation and condensation take place simultaneously and a stage is reached when the number of molecules condensing is equal to the number of molecules evaporating. After this there is no decrease in the amount of the liquid.

In order that evaporation may take place easily, it is necessary that vapour formed as a result of evaporation is removed as quickly as possible from the liquid surface. This is the reason why evaporation takes place more quickly when there is a breeze.

When there is no breeze in sultry weather, we feel uncomfortable as the perspiration does not evaporate from our bodies and we have to fan ourselves to improve the process of evaporation.

Experiment

Conduct an experiment in the following way. Take a thin glass flask and attach a small glass tube to it. It is connected by a rubber tube to a pressure gauge. Place a piece of cloth soaked in alcohol or ether on the top of the flask as shown in Fig. 6.8. When the ether evaporates from the cloth, its temperature falls. It also cools the air inside the flask causing a reduction in its volume which is clearly indicated by the rise in the liquid level in the manometer.

If a person is running a high temperature, a piece of cloth soaked in eau-de-cologne is placed on his forehead, to bring down the temperature. When eau-de-cologne is not available,

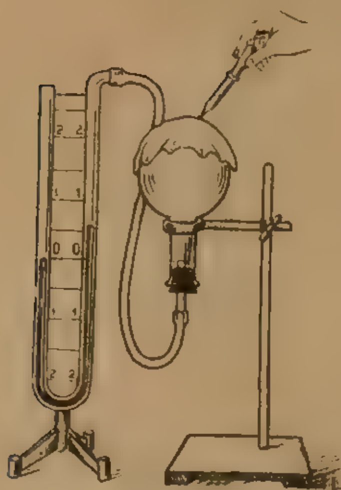


Fig. 6.8. Evaporation cools a liquid

generally a piece of cloth soaked in water is used in its place and one uses a fan to ensure that there is quick evaporation and it is observed that the temperature of the person goes down. These experiments show that cooling is caused by evaporation.

So far we have discussed about evaporation from a liquid. It can take place even in a solid. A solid like camphor evaporates quickly without passing through the liquid state.

When you heat some iodine crystals inside a closed test-tube and allow them to evaporate, the coloured vapour of iodine fills the tube and shows clearly how the solid is changed into vapour. This process in which a solid changes directly to the vapour state is known as **sublimation.**

You have seen the condensation of water vapour present in the atmosphere during the night so that the dew is observed on the surface of grass early in the morning.

We have discussed earlier in this section that evaporation takes place continuously from the surface of rivers and seas. When water vapour is carried to a great height, it cools and condenses again into tiny drops of water which collect together to form clouds.

Exercise

1. If there is no blotting paper to dry the ink dropped on a white paper, what should you do ?

2. Why is it easier to bear the heat in a dry climate than in a humid one ?
3. An earthen pitcher keeps water cool in summer. Explain.
4. When a person wears wet clothes, a cooling effect is experienced by his body. Explain.
5. Evaporation causes cooling. Explain with the help of a suitable experiment.
6. Wet linen and muddy roads dry more quickly in summer than in winter season. Why ?
7. A piece of wet linen is applied on the forehead of a person and a fan is used, when he is running high temperature. Why ?
8. Explain why a perspiring person feels cool when he sits under a fan.
9. Take a small quantity of naphthalene and powder it. Leave the powdered naphthalene on a saucer and allow it to sublimate. Write down the date of the beginning of the experiment and determine how long it takes to sublimate.
10. Condensation is the reverse process of evaporation. Explain fully.

§ 71. Boiling

We have mentioned earlier that there are two processes by which vaporization takes place. So far, we have been discussing evaporation. We will now consider the other process of vaporization which is called boiling.

Experiment

Take a thin walled glass flask partly filled with cold water. When it is heated and the temperature rises, you will notice air bubbles rising from the bottom of the vessel. As these bubbles rise, their size increases. These air bubbles are due to the air

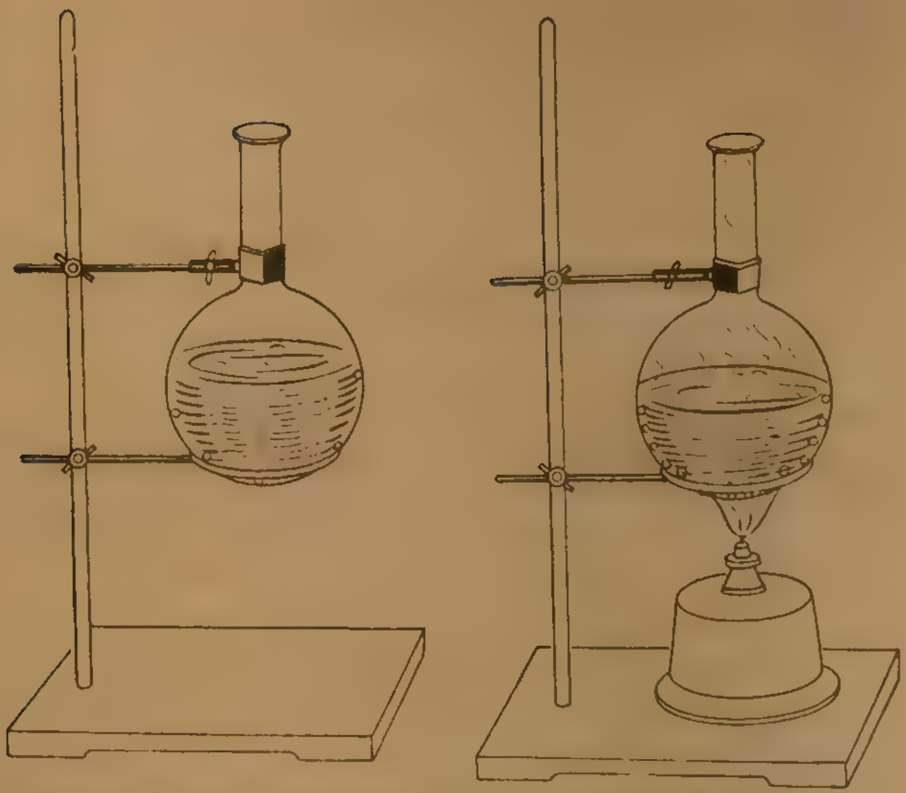


Fig. 6.9. Air bubbles are formed on the walls of a vessel containing water when the latter is heated

which was dissolved in the cold water. Air dissolves more in cold water than in hot water (Fig. 6.9).

As soon as a small bubble of air is formed at the bottom or side walls of the vessel, evaporation takes place from the water surrounding the bubble. The bubble, therefore, contains partly air and partly water vapour and grows in size. In accordance with Archimedes' Principle, an upward force acts on the bubble and when this force is greater than the force holding the bubble to the wall of the vessel, the bubble is detached from the wall and rises to the water surface, where it escapes into the atmosphere (Fig. 6.10).

As the temperature of the water rises, the rate of evaporation of

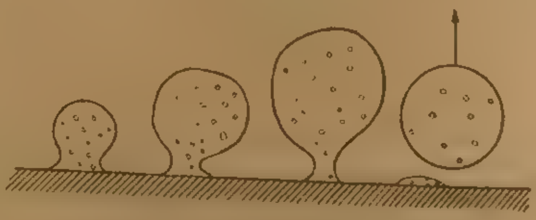


Fig. 6.10. How the bubble detaches from the wall of the vessel

water increases with the result that the bubble increases in size quickly. When the temperature of the water reaches 100°C, the bubbles, sticking to the cracks or other uneven places in the walls of the vessel, increase in size due to evaporation very quickly and when the vapour pressure of the liquid becomes equal to the atmospheric pressure, the vigorous formation of bubbles takes place. This process is known as **boiling** (Fig. 6.11).

Fig. 6.11. Mechanism of boiling

The main difference between the evaporation and the boiling is (1) evaporation takes place from the surface of the liquid whereas boiling is due to the vapour formation inside the liquid and (2) evaporation takes place at all temperatures whereas boiling takes place at a fixed constant temperature known as the **boiling point** of the liquid.

We have already learnt that when a solid is melting, the temperature remains constant during the melting process. Similarly, when a liquid boils the temperature remains constant as shown in the graph (Fig. 6.12).

The energy that is received by the liquid when it starts boiling is utilized in overcoming the force of attraction between different molecules of the liquid. If the force of attraction is large, naturally the boiling point of a substance will be high.

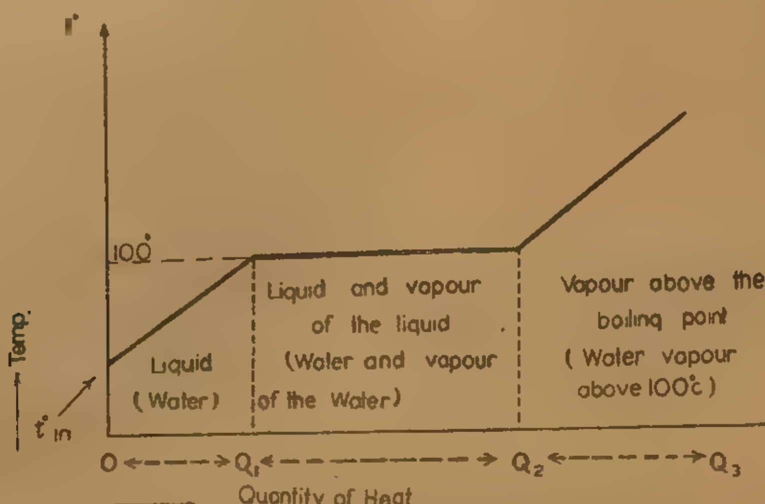


Fig. 6.12. Graph showing the temperature against the quantity of heat as a liquid is heated

During the process of boiling, the quantity of heat supplied increases the internal energy of the liquid. During the process, as there is no rise in temperature of the liquid, there is no increase in the speed of the molecules of the liquid. In other words, there is no increase in the kinetic energy of the molecules of the liquid. So, during the process of boiling, the supplied quantity of heat increases only the potential energy of the molecules of the liquid and hence there is no rise in temperature during this process.

The following table gives the boiling points of some substances in degree C.

Helium	269	Liquid Ammonia	33	Mercury	357
Hydrogen	253	Ether	35	Lead	1620
Nitrogen	196	Alcohol	78	Copper	2336
Oxygen	183	Water	100	Silver	1950
				Iron	3000

§ 72. Laboratory Work

Name: Observations of the process of boiling water.

Apparatus and material: Spirit-lamp, thin-walled glass flask, thermometer, watch (or sand-watch), stand, etc.

Procedure: Take water in a flask. Note down the temperature of the water. Start heating it and note down the temperature every few minutes. When water boils, keep on recording the temperature for a few minutes. Stop heating the water, and note its temperature for another four or five minutes.

Draw a graph between the temperature of the water and time.

§ 73. Heat of Vaporization and Condensation

We have seen that when water is changed into vapour at the boiling point, the temperature remains constant during the process. The fuel burnt in the spirit-lamp supplies heat. This quantity of heat is utilized in increasing the internal energy of the water molecules when water changes into vapour and does not produce any change in its temperature. The quantity of heat is not used in increasing the kinetic energy but the potential energy of the water molecules. It is, therefore, called **latent heat of vaporization.**

You have learnt earlier that when one gram of a solid is changed into liquid at its melting point, the

quantity of heat required is called the latent heat of fusion. **The heat of vaporization of a liquid is the quantity of heat required to change one kilogram of a liquid into vapour at its boiling point.** Experimental results show that 540 calories of heat is required to change 1 g of water at 100°C into steam without producing any change in temperature. The heat of vaporization is measured in the unit of either cal/g or kcal/g

Heat of vaporization measures the increase in the internal energy of a liquid when it is changed into vapour. Thus, we can say that the energy of 1 g of steam at 100°C is 540 cal more than that of 1 g of water at 100°C.

The following table gives the value of heat of vaporization of some liquids at their respective boiling temperature and at normal atmospheric pressure.

Water	—540 cal/g
Alcohol	—204 cal/g
Ether	— 84 cal/g

The quantity of heat required to transform a liquid at its boiling temperature into its vapour state is equal to the product of the mass m of the liquid and its heat of vaporization, L. If this quantity of heat required is devided by q, we have.

$$\boxed{q = L \times m}$$

Experiment

Conduct an experiment in the following way. Take water in a glass flask and boil it. Steam produced inside the flask comes out of the glass tube. Keep a metal plate suspended from a support as shown in Fig. 6.13. The metal surface acts as a cold

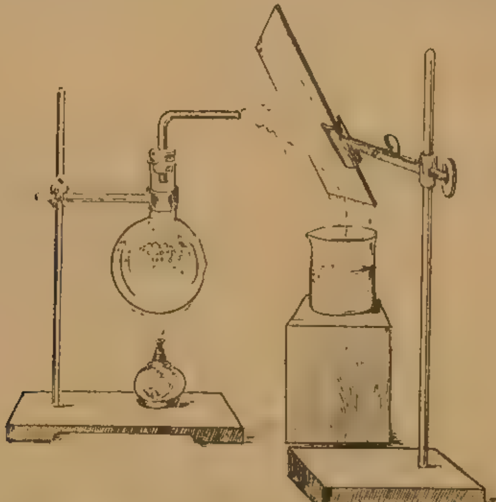


Fig. 6.13. Condensation of water vapour on metal surface

object because you may have noticed that when we touch a metal surface at low temperature, it appears to be cold.

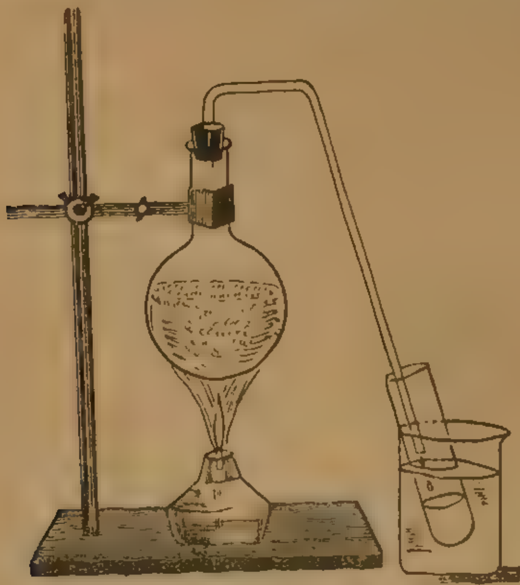


Fig. 6.14. Condensation of water in a test-tube cooled by water. The condensed vapour heats the water in the glass

A glass beaker is kept on a stand just below the metal plate. The steam, when it comes in contact with the cold object condenses into water droplets and the water drops are collected in the beaker.

Try to do another simple experiment where the glass flask in which water is boiled is fitted with a narrow tube, bent at an angle so that the longer arm of the tube goes inside a test-tube as shown in Fig. 6.14.

The test-tube is kept immersed in a glass beaker containing cold water as shown in Fig. 6.14. Note down the temperature of the water in the glass beaker before the experiment and also after the steam is condensed inside the test-tube. You will find that there is a rise in the temperature of water in the beaker.

These two experiments show that when steam condenses and changes into water, considerable amount of energy is given off. It also shows that this heat was in the steam because when water was changed

into steam it absorbed the latent heat of vaporization.

The same thing is expressed in the following statement.

If one gram of steam is condensed into water at its boiling point, i.e., 100°C, its internal energy is reduced by 540 cal.

We have described earlier how convection of hot water is utilized in the central water heating system. Sometimes in central heating systems, steam is passed through the pipes in place of water. The steam, while passing through the radiators, heats up different rooms in the building. When it gives off the necessary heat, it changes into water.

Exercise

1. What do you understand by the statement that heat of vaporization of steam is 540 cal/g ?
2. Why is it more dangerous when a person gets burnt by steam at 100°C, than water at the same temperature ?
3. Calculate the heat required to turn 50 g of water into steam at 100°C.
4. When vapour is changed into liquid, it releases as much heat as was required to form it. Explain.
5. What do we mean when we say that the heat of condensation of liquid ammonia is 327 cal/g ?
6. How much energy is released by 1 kg of steam at 100°C when steam is changed into water and cooled to 0°C ? Express this energy in joules.
7. Which of the substances listed in the table increase their energy most when turned from liquid into vapour ?
8. Liquid ammonia is evaporated in refrigerators to obtain ice. How much ammonia has to be evaporated to obtain 10 kg of ice at 0°C from 10 kg of water at 20°C ?
9. Modern boilers produce 220 tonnes of superheated steam in an hour. How much heat does the boiler receive per hour if 807 kcal are spent in forming 1 kg of steam ?

§ 73. Effect of Pressure on the Boiling Point

Boiling at Reduced Pressure

The influence of pressure on the boiling point of water can be shown by the following experiment. Take a flask half filled with water and boil the water vigourously for sometime to remove the air inside the flask. Remove the flask from the flame and insert a cork, so that there is no air inside it. Invert the flask and pour cold water over it (Fig. 6.15). This cold water

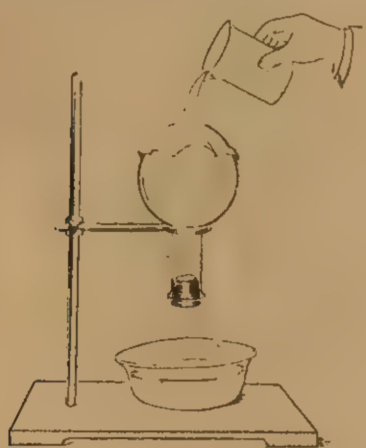


Fig. 6.15. Boiling of water under a reduced pressure

causes some of the vapour in the flask to condense. The pressure on the hot water in the flask is reduced sufficiently to allow the water to boil again.

The same thing can be shown by another experiment. Take a glass of water and boil it so that its temperature rises to 100°C. The spirit-lamp is then removed and the temperature is allowed to drop to 80°—70°C. The glass of water is quickly transferred and kept under a bell-shaped jar which is connected to an air pump so that air is taken out from the bell-jar. The water starts boiling under the reduced pressure (Fig. 6.16). This shows that the boiling

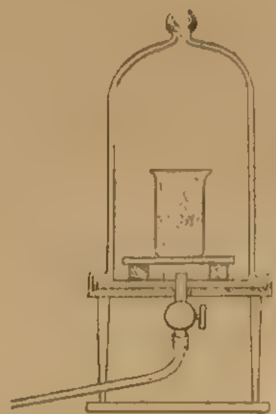


Fig. 6.16. When pressure is reduced, water boils at a reduced temperature

point of a liquid depends upon the pressure on the surface of the liquid.

At great heights, like mountains, the atmospheric pressure is low, and water boils at a much lower temperature than 100°C. At Darjeeling water boils at about 94°C. At high temperatures, cooking is much quicker than at low temperatures. That is why on mountains, it takes much longer to cook food than on the plains.

In the pressure cooker, the increased pressure raises the boiling

point of water which means a higher cooking temperature and the time of cooking is reduced.

When milk is to be evaporated or is to be thickened, it is done in a way so that boiling is carried out at a reduced pressure.

This is utilized in sugar refineries where the solution is boiled at a reduced pressure and at a low temperature, thus preventing the burning of sugar.

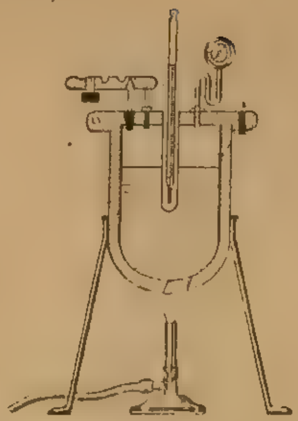


Fig. 6.17. Boiling of water at increased pressure

Boiling at Higher Pressure

When water is heated in a closed vessel, the pressure inside the vessel increases, because the molecules that change into vapour are not free to disperse in the outside medium and the boiling point of water does not remain at 100°C. Here, an apparatus, used as boiler, is made of a metallic vessel and the lid is fixed to the vessel so that there is no leakage. When water is boiled in the vessel, it cannot escape through the lid which is fixed to the vessel by means of screws. The arrangement is shown in Fig. 6.17. At the centre of the lid there is a metal tube soldered to the lid and going inside. The length of the tube is such that it is well inside the level of water. A thermometer is placed inside the tube thus recording the temperature of water. There is a safety valve attached to the lid by a lever. A weight is placed on the lever which presses the safety valve so that the steam cannot escape through it under the normal conditions. There is a pressure gauge which indicates the pressure inside the boiler. When water is heated in this apparatus, it is found that the water does not start boiling even if the temperature of water inside is more than 100°C. When the water is heated more and more, the pressure inside increases and when the pressure inside the boiler is greater than the pressure exerted by the weight attached to the lever, the safety valve opens and allows the steam to escape. This lowers the pressure inside and the liquid starts boiling and the thermometer records a constant temperature. If the weight attached to the lever is moved away from the valve, it presses the valve more, thus preventing the steam to escape. The quantity of steam inside the boiler increases and conse-

quently, the pressure inside the boiler also increases. The boiling starts again at a still higher temperature. It shows that the boiling point of a liquid is increased if the pressure on the liquid is also increased.

It has some applications, especially in engineering where boilers are provided with safety valves. The boilers are constructed so that they can withstand upto a certain maximum pressure. The function of the safety valve is to guard against an excessive increase of pressure inside the boiler. It is generally indicated on the lever of the safety valve by a marked line.

Doctors sterilize their surgical instruments in such closed steam boxes so that all bacteria are destroyed there at the high temperature attained. Steam at a high temperature is used for washing linen and clothes in the hospitals so that all germs are destroyed.

Exercise

1. On mountains, meat cannot be cooked in an open sauce pan. Why ?
2. Is it possible to boil water at 70°C ? Describe an experiment to show that water can be boiled at 70°C.
3. What is the effect of pressure on the boiling point of water ?

Summary and Conclusions

1. In nature, a body exists in three states: (i) solid, (ii) liquid and (iii) gas.
2. The particular state of any substance depends upon its temperature.

   For example, water at temperature below 0°C exists in solid state, in the temperature range of 0°—100°C it exists in liquid state and above the temperature of 100°C, it exists in gaseous state.
3. There are two groups of solid bodies: (i) crystalline and (ii) amorphous.
4. Melting is a process of change of state of a body from its solid to liquid state.

   The crystallization is the reverse process of melting.

5. All crystalline bodies melt at a definite temperature under normal atmospheric pressure. This definite temperature is known as the temperature of melting.

6. All crystalline bodies crystallize at a definite temperature under normal atmospheric pressure. This definite temperature is known as the temperature of crystallization.

7. The temperatures of crystallization and melting for the same substance are the same.

8. During the process of melting, same quantity of heat is required whereas during the process of crystallization, same quantity of heat is given off.

9. Heat of fusion is the quantity of heat required to change 1 kg of crystalline body to its liquid form at its melting temperature (*without any change in temperature*).

10. Heat of fusion is measured either in cal/g or Kcal/kg.

11. The quantity of heat required to melt completely a certain quantity of substance is calculated by the following formula:

    $q = L \times m$, where L is the heat of fusion of the body and m is its mass.

12. Heat of crystallization is the quantity of heat given off by 1 kg of substance during the process of crystallization at constant temperature (temperature of crystallization).

13. Heat of fusion and the heat of crystallization of the same substance are equal.

14. The quantity of heat given off by same quantity of liquid during the process of crystallization is calculated by the following formula:

    $q = L \times m$ where L is the heat of crystallization of the body and m is the mass of the body.

15. The fact that same heat is required to change the state of a substance from crystalline to liquid state without change in temperature indicates that 1 g of a substance in liquid state has more energy than 1 g of the same substance in crystalline form at the same temperature (the temperature of fusion).

16. The process of vaporization takes place in two ways: (i) by evaporation and (ii) by boiling.

17. Evaporation is the process of vaporization taking place only form the surface of the liquid at all temperatures.

18. The speed of evaporation depends upon the following factors:

    (a) the temperature of the liquid,

    (b) the area of the free surface of the liquid,

    (c) property of the liquid,

    (d) the speed of motion of air over the surface of evaporating liquid.

19. Evaporation causes the fall in temperature of the evaporating liquid.

20. The reverse process of evaporation (change of state from vapour to liquid) is known as condensation. In the process of condensation, same quantity of heat is given off.

21. Boiling is the process of change of state from liquid to vapour state at a constant temperature under normal atmospheric pressure. This constant temperature is known as the boiling point of the liquid.

    Boiling takes place throughout the whole liquid.

22. The heat of vaporization of a liquid is the quantity of heat required to change 1 kg of liquid to its vapour form at its boiling point.

    The heat of vaporization is measured either in cal/g or Kcal/kg

23. The quantity of heat required to change a certain quantity of liquid in its vapour at its boiling point is calculated by the following formula:

    $q=L\times m$, where L is the heat of vaporization of the liquid m is the mass of the liquid.

24. The fact that same heat is required to change the state of a substance from liquid to gaseous form without any change in temperature, indicates that 1 g of vapour of a substance

possesses more internal energy than 1 g of liquid of the same temperature (temperature of boiling).

25. The boiling point of a liquid depends upon the external pressure on its vapour. By increasing outside pressure, the boiling point is increased and *vice versa.*